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December 1994

US Army Corps of Engineers
Waterways Experiment Station

Subsurface Site Characterization — Proceedings of Research Needs Workshop

Compiled by *M. K. Corcoran*
T. H. Grau

Prepared for Headquarters, U.S. Army Corps of Engineers

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U.S. Army Corps of Engineers
Waterways Experiment Station
3909 Halls Ferry Road
Vicksburg, MS 39180-6199

Final report

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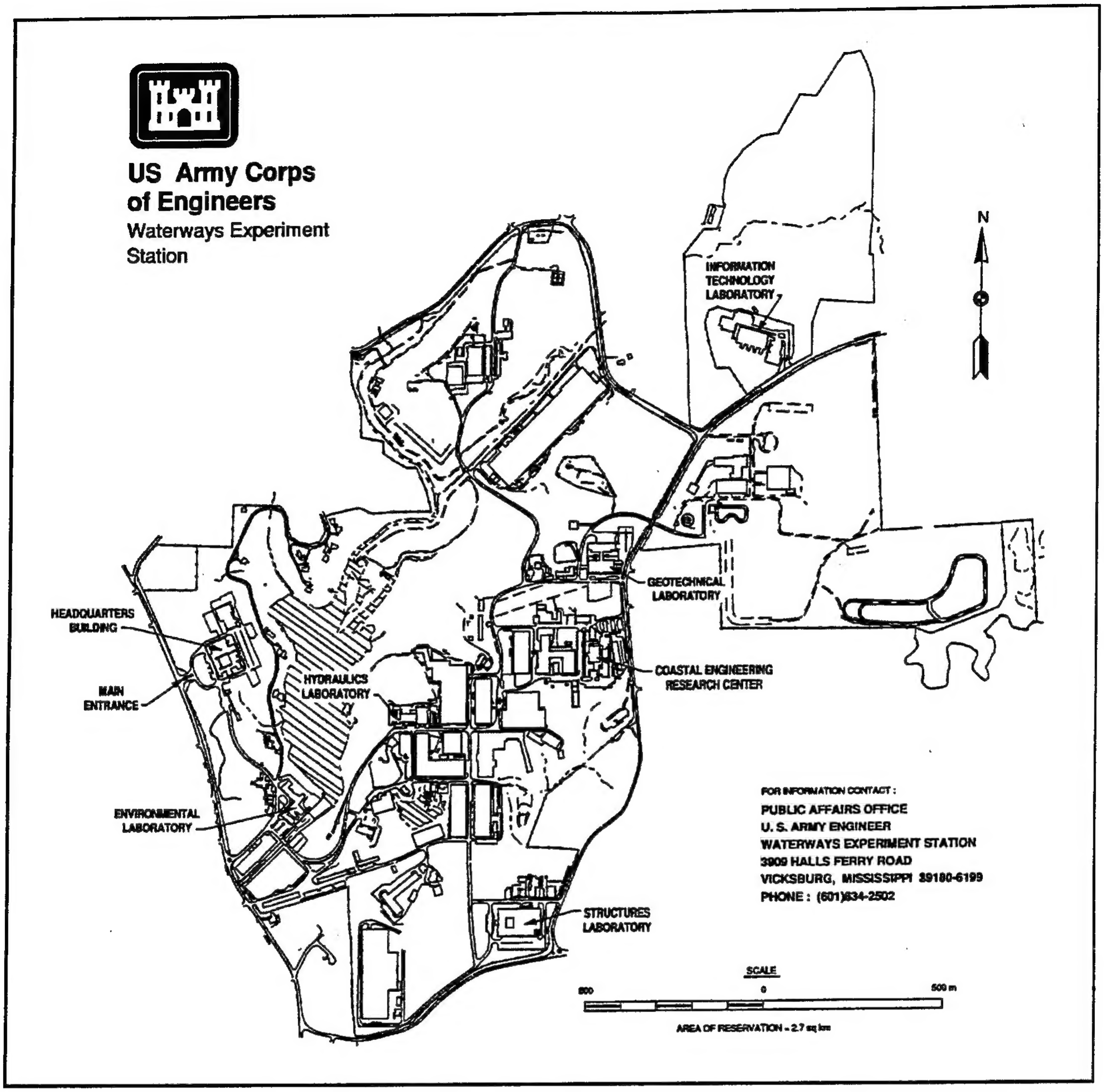

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Contents

Preface

The Proceedings of the Subsurface Site Characterization Research Needs Workshop were prepared for the Headquarters, U.S. Army Corps of Engineers (HQUSACE), by the U.S. Army Engineer Waterways Experiment Station (WES).

The workshop and subsequent research were conducted under Funding Authorization Document (FAD) Advice Numbers 93080112, 93080113, and 93080114, dated 20 September 1993, 20 September 1993, and 27 September 1993, respectively. Headquarters, Army Materiel Command (AMCRD-N), is the sponsor for the following research. WES has been tasked with the tunnel detection mission for the U.S. Army by a Memorandum of Understanding between WES and the Army Counter-Drug RDA Office, dated 27 September 1993.

The Program Manager for tunnel detection research at WES is Mr. R. F. Ballard, Earthquake Engineering and Geosciences Division (GG), Geotechnical Laboratory (GL). The research was conducted under the supervision of Dr. Arley G. Franklin, Chief, GG, and Dr. William F. Marcuson III, Director, GL. Ms. M. K. Corcoran and Mrs. T. H. Grau, CEWES-GG, compiled information for workshop manuals and summary proceedings. Presentations at the workshop were made by R. F. Ballard, R. D. Bennett, CEWES-GS, D. K. Butler, CEWES-GG, C. Cameron, University of Southern Mississippi, M. K. Corcoran, J. B. Dunbar, CEWES-GG, G. Hennington, Information Management Systems, R. J. Larson, CEWES-GG, and D. Yule, CEWES-GG. A court reporter recorded and transcribed the technical presentations and general discussions.

The following report is a summary of presentations and discussions on state-of-the-art technologies and strategies for tunnel detection. The workshop consisted of presentations by WES scientists (i.e., geologists and geophysicists) to managers and field personnel from various law enforcement agencies (LEA), defense and military organizations, and judicial and executive branches of the federal government. Attendees at the workshop included personnel from the U.S. Army Drug Enforcement Agency (DEA), Federal Bureau of Investigation (FBI), U.S. Border Patrol, Customs Service, Central Intelligence Agency (CIA), Department of Justice, and the Executive Office of the President.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Bruce K. Howard, EN.

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Conversion Factors, Non-SI to SI Units of Measurement

Non-SI units of measurement used in this report can be converted to SI units as follows:

Multiply	By	To Obtain
feet	0.3048	meters
inches	2.54	centimeters
miles (U.S. statute)	1.609347	kilometers
tons (2,000 pounds, mass)	907.1847	kilograms

ORGANIZATION ABBREVIATIONS
Subsurface Site Characterization Research Needs Workshop, Vicksburg, Mississippi, 5-6 January 1994

Abbreviation	Organization
AF-BMO	Air Force Ballistic Missile Office
AMCRD-N	Army Materiel Command
BRAC	Base Realignment and Closure
BRDEC	Belvoir Research, Development and Engineering Center
CD-RDA	Counter-Drug Research, Development and Acquisition Office
CEWES	U.S. Army Engineer Waterways Experiment Station
DEA	Drug Enforcement Agency
DOD	Department of Defense
DOJ/INS	Department of Justice/Immigration and Naturalization Service
DOT/FHWA	Department of Transportation/Federal Highway Administration
FBI	Federal Bureau of Investigation
HQAMC (AMCRD-N)	Army Materiel Command
HQDNA/TASS	Headquarters, Defense Nuclear Agency/Technology Applications System Survivability
HQUSACE	Headquarters, U.S. Army Corps of Engineers
JTF-6	Joint Task Force Six
ONDCP	Office of National Drug Control Policy
SARDA	Secretary of the Army for Research, Development, and Acquisition

Introduction

The Subsurface Site Characterization Research Needs Workshop was held at the U.S. Army Engineer Waterways Experiment Station (WES) on 5-6 January 1994. The workshop was sponsored by Funding Authorization Document (FAD) Nos. 93080112, 93080113, 93080114.

The purpose of the workshop was to define research needs of various law enforcement agencies and to determine the direction of this research. A combined strategy employing the capabilities of the scientific field with law enforcement experience can accelerate the development of low profile technology focused on the subsurface for detection of clandestine tunnels.

The workshop also promoted dialogue between scientists and law enforcement agents to develop two-way communication for the exchange of ideas. Scientific presentations outlined a proposed research plan and a panel discussion consisted of representatives from various law enforcement agencies who critiqued and offered constructive criticism of the plan.

These *Proceedings* contain the record of presentations and panel discussions. Pertinent discussions that followed presentations are also included.

WES gratefully acknowledges the contributions of the federal agencies who participated in the two day workshop.

ATTENDEES
Subsurface Site Characterization Research Needs Workshop
Vicksburg, Mississippi 5-6 January 1994

Name	Organization	Address
Ross L. Amico	HQ DNA/TASS	6801 Telegraph Road Alexandria, VA 22310
Angie Amrich	Waterways Experiment Station	CEWES-GG-YG 3909 Halls Ferry Road Vicksburg, MS 39180
Robert F. Ballard	Waterways Experiment Station	CEWES-GG 3909 Halls Ferry Road Vicksburg, MS 39180
Carlos J. Barron	FBI	P.O. Box 2910 Tucson, AZ 85702
Dave Bennett	Waterways Experiment Station	CEWES-GS-R 3909 Halls Ferry Road Vicksburg, MS 39180
Chris Cameron	Univ. of Southern Mississippi	Box 5044 Hattiesburg, MS 39406
Boyce Campbell	Office of National Drug Control Policy	CTAC Executive Office of the President Washington, D.C. 20500
Larry Caver	U.S. Border Patrol	LNO/FTF-6 Operation Alliance P.O. Box 8051, Biggs AAF El Paso, TX
Robert C. Claborn	U.S. Customs Service	406 Virginia Avenue San Ysidro, CA 92173
Maureen K. Corcoran	Waterways Experiment Station	GG-YG 3909 Halls Ferry Road Vicksburg, MS 39180
Louis Cross	U.S. Border Patrol	2766 Via Orange Way, Suite C Spring Valley, CA
Joe Dunbar	Waterways Experiment Station	CEWES-GG-YG 3909 Halls Ferry Road Vicksburg, MS 39180
James R. Geddes, II	U.S. Customs Service	Office of Enforcement RAC-McAllen 1701 West Boxx Hwy 83 Suite 508 McAllen, TX 78501
Richard Gorman	Drug Enforcement Administration	San Diego Division 402 W. 35th Street National City, CA 92050
Tina H. Grau	Waterways Experiment Station	CEWES-GG 3909 Halls Ferry Road Vicksburg, MS 39180

Jeff Harsanyi	DOJ/INS Research & Development	Room 6042 425 1st N.W. Washington, D.C. 20536
Bill Heineman		14416 Brookmead Drive Germantown, MD 20874
Gary Hennington	Information Management Systems	1608 Chambers Street Vicksburg, MS 39180
Andrew Kirby	Office of Research & Development	Room 6042 425 1st N.W. Washington, D.C. 20536
Robert Larson	Waterways Experiment Station	CEWES-GG-YG 3909 Halls Ferry Road Vicksburg, MS 39180
Col. R. J. Lunsford, Jr.	HQ AMC (AMCRD-N)	5001 Eisenhower Avenue Alexandria, VA 22333
Alexander Mondrick	U.S. Army Communications	Electronics Command AMSEL-RD-AS-TD Fort Monmouth, NJ 07703
Warren Philipson	Office of Research & Development	6709 Woodstream Drive Lanham, MD 20706-2123
William J. Sulak	HQ AMC (SARD-FCN/AMCRD-N)	5001 Eisenhower Avenue Alexandria, VA 92173
William Tatu	U.S. Border Patrol	7060 Boeing Street San Diego, CA 92173
Jack Trela	Operation Alliance - FBI Rep.	P.O. Box 8051 Biggs Army Airfield El Paso, TX
Gerald G. Tucker	U.S. Army Missile Command	AMSMI-CIC-CD Redstone Arsenal, AL 35898-7462
Don E. Yule	Waterways Experiment Station	CEWES-GG-YG 3909 Halls Ferry Road Vicksburg, MS 39180

AGENDA
Subsurface Site Characterization Research Needs Workshop
Conference Room 1054, Building 3396
Waterways Experiment Station, Vicksburg, Mississippi

Time	Presentation	Speaker
5 JAN 94		
0800	Welcome and Intro to Workshop	R. W. Whalin/COL Howard Waterways Experiment Station
0810	WES 3-Screen Briefing	
0900	Overview/Purpose	Bob Ballard Waterways Experiment Station
0930	Geologic Principles	Bob Larson Waterways Experiment Station
1000	Clandestine Tunnel Operations	Chris Cameron Univ. of Southern Mississippi
1045	Break	
1100	Modern Tunneling Technology	Dave Bennett Waterways Experiment Station
1130	Detection of Tunnels	Dwain Butler Waterways Experiment Station
1215	Lunch	
1300	Border Conditions/Tactical Constraints	Panel Discussion
1330	Otay Mesa Geophysical Test Results	Don Yule Waterways Experiment Station
1415	Geologic Criteria	Maureen K. Corcoran Waterways Experiment Station
1445	Break	
1500	Computer Applications	Joe Dunbar/Gary Hennington Waterways Experiment Station/ Information Management System
1600	Search Strategy	Don Yule Waterways Experiment Station
1900	Dinner in the Jeff Davis Room, Park Inn	

AGENDA
Subsurface Site Characterization Research Needs Workshop
Conference Room 1054, Building 3396
Waterways Experiment Station, Vicksburg, Mississippi

Time	Presentation	Speaker
6 JAN 94		
0800	Previous Day Summary	Bob Ballard Waterways Experiment Station
0830	Research Needs Panel Discussion	COL R. Lunsford, moderator HQ AMC (AMCRD-N)
1000	Break	
1015	Continuation of Panel Discussion	
1115	Participant Comments	
1130	Wrap-up/Recommendations	Bob Ballard Waterways Experiment Station
1150	Closing Comments	COL B. Howard Waterways Experiment Station

Subsurface Site Characterization (Tunnel Detection)

Mr. Robert F. Ballard, Jr.
Waterways Experiment Station

Abstract

The Waterways Experiment Station (WES) in Vicksburg, Mississippi, has been involved in cavity and tunnel detection since the mid-1970's. WES was a major supporter of the Belvoir Research Development and Engineering Center's tunnel detection mission in Korea since the mid-1980's when the program was reviewed. In view of the fact that Belvoir was on the Base Realignment and Closure (BRAC) 1993 list, Army Materiel Command (AMC) made the decision to relinquish the entire tunnel detection mission, both foreign and domestic. The Corps of Engineers was requested by the Counter-Drug Research, Development, and Acquisition Office (CD-RDA) to assume responsibility of the mission. Fort Belvoir had been involved in the domestic counter-drug aspect of this problem since 1991 and had four systems under contract to develop products concerned with data collection and fusion: the 3-D high resolution reflection seismic system, an electromagnetic search system, a synthetic pulse ground penetrating radar, and a data analysis and interpretation system involving artificial intelligence and neutral networks.

WES formed a site characterization team of geologists and geophysicists to continue this work and to develop additional research goals. A large-scale border reconnaissance using surface and airborne methods would aid in monitoring changes in the landscape. Emphasis on such detection techniques would be on speed and low profile characteristics of the equipment. A tunnel detection test bed is recommended utilizing the Otay Mesa, California, tunnel site to test emerging and existing technology such as seismic, frequency and time domain electromagnetics, gravity gradiometery, and electrical techniques. Modest funding has been allocated for FY94. Future funding would ensure the actual field testing and the optimization of these particular products if such can be made available.

Discussion

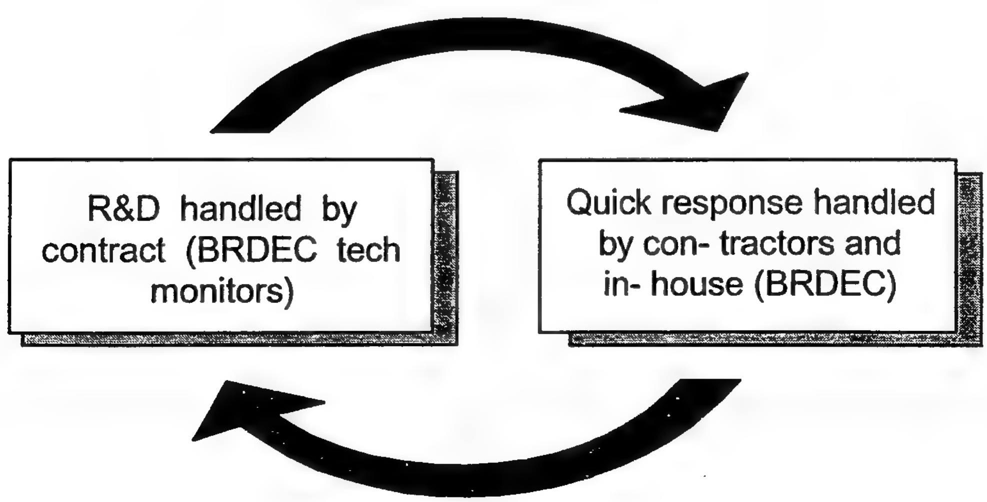
LEA: Do you expect FY94 funding to come out of the Counter-Drug Office?

SCIENTIST: At this time, the source of funding is SARDA. Combatting subsurface drug smuggling activities is the only way of keeping the tunnel detection mission alive since the Army declared there would be no future tunnel research in Korea beyond FY93. Hopes for funding would include $500K for FY94 and possibly the same for FY95. In 1995, the funding would be directed toward the actual field testing of delivered products.

Executive Summary

- WES involved in cavity/tunnel detection since mid 70's
- WES a major supporter of BRDEC's tunnel detection mission in Korea since mid 80's
- BRDEC is on BRAC '93 List
- AMC to relinquish tunnel detection mission
- CE (WES) requested by AMC (SARDA) to take on tunnel detection mission
- Transition plan developed
- Time frame - 17 August - 31 December 93

Past and Present
CD RDA and JTF-6 Support



R&D Program Status

Products Under Development

Data Collection:

- 3D Seismic Search System (3DS)
- EM Re-Radiation Search System (ERS)
- Synthetic Pulse Radar Search System (SPR)

Data Analysis/Interpretation:

- Data Analysis System (DAS)

R&D Contracts

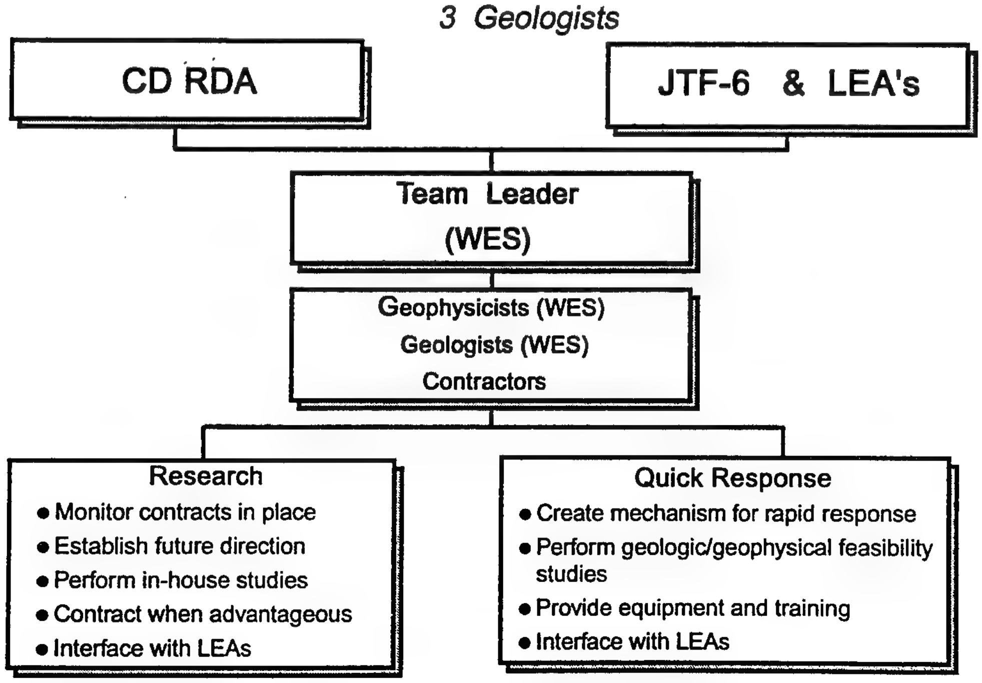
Task Title	Contractor/ Location	Award Total	Award Date	Delivery Date
ERS	Arizona U Tucson, AZ	200K	09/92	09/94
3DS	DOE-Geotech Gr Junction, CO	255K	12/92	08/94
SPR	ENSCO Melbourne, FL	207K	03/93	08/94
DAS	ORINCON San Diego, CA	243K	02/93	09/94

Primary Thrusts of Mission Transition Plan

- Establish WES Site Characterization Team
- WES provides coordinated support to CD RDA and JTF-6
- CD RDA provides guidance, oversight, and R&D funding
- Collaboration in formation of future R&D needs

WES Site Characterization Team Functions

Team Complement: 3 Geophysicists
3 Geologists



Future Research Approach

- Simple and practical
  - Emphasis on surface and overhead search techniques
  - Speed
  - Low profile
- Avoid duplication
  - Identify parallel efforts by others
  - Combine resources

Future Research Thrusts

- Large-scale border reconnaissance
  - Surface and airborne methods
  - Periodic monitoring for baseline changes
- Develop low-profile rapid methods
- New efforts employing emerging technology
  - Low-frequency electrical methods
  - Airborne, waterborne, surface EM
  - Magnetic and gravity gradiometric methods
- Innovative passive listening systems
- Active profiling methods (land / air / waterborne)
  - Seismic
  - Time domain EM
  - Frequency domain EM
  - Electrical
- Multispectral imagery
- High risk / high payoff ideas
  - "Star Wars" approach
  - Balance immediate and long-term needs
  - Solicit defense industry "secret" technology

Recommended Allocation of CD RDA FY 93 Funds

($500K Available)

- **Perform geologic studies to predict tunneling methods at prioritized sites - $200K**
  - Location of old/new near-border mines
  - Geology / Geochemistry / Geophysics
  - Engineering parameters
- **Complete FY 92 contracts - $200K**
  - Review progress
  - Evaluate results
  - Recommend add-on phases
  - Fund final task of Data Analysis System ($100K)
- **Evaluate applications of waterborne geophysics - $100K**
  - Rio Grande feasibility study
  - Applicable technique for target type
  - Implementation methods

Schedule

- FY 94
  - **Direct 93 funding toward**
    - Geologic studies
    - Contract Wrap-up
    - Waterborne geophysics
  - **Direct 94 funding toward**
    - Field test planning
    - "Research Needs" workshop
    - Action on identified "Needs"
- FY 95
  - **Direct 95 funding toward**
    - Field testing
    - Product optimization / implementation
    - New research

Geologic Principles

Mr. Robert J. Larson
Waterways Experiment Station

Abstract

Excavation of earth materials (rock) is influenced by the composition of material, orientation of material units, heterogeneity and extent of disturbance (folding and faulting). Rock and character are functions of the environment of formation and chemical composition. Since the earth's formation about 5 billion years ago, forces within the earth have been redistributing and reforming rock materials. Observations made in the field can provide insight to the extent of rock homogeneity, permeability, extent of fracture/folding and resistance to excavation. These factors all influence the feasibility (success or failure) and techniques of excavation (jack-hammer, blasting, etc.). Each of the three rock types form under a variety of conditions. These conditions vary widely within each type and with respect to one another. The generalized conditions of formation are:

Igneous rocks - solidified molten material
Metamorphic rocks - intense pressure and heat, without melting
Sedimentary rocks - cemented particles of pre-existing rock materials or chemical precipitates (ocean environments, biological or groundwater)

When exposed at the surface or near the surface, the rocks undergo processes of weathering caused primarily by water and atmospheric gases. Weathering produces a less competent (weaker) rock. Weathering is also enhanced by rock fractures, permeability, and duration of time exposed to the weathering conditions. All the factors of rock fracture, weathering and orientation influence excavation. In the instance of tunneling, well cemented sedimentary rocks, unweathered igneous and metamorphic rock, and unfractured rocks of all types can typically maintain moderate to small openings without much support structure. Perhaps the greatest deterrent to tunneling is high permeability (rock and fractures) allowing flooding of the excavation, highly weathered rock having little strength to support overlying rock masses, and incompetent rock that spalls or readily fragments/separates.

DISCUSSION

LEA: Has the United States Geological Society (USGS) compiled maps that indicate where tunnels are most likely to be constructed?

SCIENTIST: There are numerous geologic maps available not only for federal and state agencies but also for private industries involved in mineral and water surveys, and soils investigations. The problem is getting the data assembled quickly so that an estimation of where tunnels may be located can be determined. A geologic comparison between the two tunnels that have been located in Douglas, Arizona, and in Otay Mesa, California, has not yet been completed. Although construction may be similar, the rock type is not the same. The tunnel locations were determined primarily by accessibility and the amount of construction on both sides of the border. The common factor between the two tunnels is that explosive demolition agents were not used to build them. The ground at both sites is soft but cohesive.

LEA: The bottom depth on the southern side of the Otay Mesa, California, tunnel was 65 ft[1] and approximately 35 ft on the north side. It was gradually sloped and ran almost 1,500 ft. The tunnel at Douglas, Arizona, was concrete lined. Only a section of the Otay Mesa tunnel (the position that supposedly was under a road bed) had been lined with concrete. The 4-in. shoring at the top in this section may have been just a precaution. The height of the Otay Mesa tunnel was approximately 5 ft and was serviced by rail carts. They (the people who constructed the tunnel) had set 2 x 4's in concrete and the floor was relatively flat. The carts had rubber tires and wheels on the sides to allow them to go through the tunnel.

Discussion then followed concerning the location of the Douglas, Arizona, tunnel on an early Army map. There is a cultural component to tunnel activity that needs to be considered. Some of the earliest information on one tunnel was in the Mexicali, Mexico, area and involved transporting Chinese across the border possibly in the 1920's and 1930's. Technically, these tunnels are the railroads. There are also rumors that Chinese were smuggled through a tunnel in El Paso, Texas, and supposedly came up into a hotel. There has been drilling in the areas where these tunnels were believed to have been located. A network of tunnels in Tijuana, Mexico, were old storm drains and have been long since abandoned. They did not extend into the United States.

[1]A table of factors for converting non-SI units of measurement to SI (metric) units is presented on page vi.

GEOLOGIC PRINCIPLES

I. MINERALS

II. ROCK MASS CLASSIFICATION AND DESCRIPTION

SEDIMENTARY, METAMORPHIC AND IGNEOUS ROCKS.

COMPOSITION AND TEXTURE

III. ROCK MASS DISCONTINUITIES

STRUCTURAL - FAULTS, JOINTS, AND SHEARS.

LITHOLOGIC - CONTACTS, FACIES, ETC.

SPECIAL ASPECTS OF ROCK MASSES

SOLUTION FEATURES AND CAVITIES

INTRUSION - IGNEOUS ROCK MASS INTRUSIONS

VEINS - JOINT OR FRACTURE FILLINGS

IV. STRUCTURAL GEOLOGY

FOLDS - ANTICLINES AND SYNCLINES

FAULTS - NORMAL AND REVERSE

V. GROUNDWATER

VI. GEOMORPHOLOGY

VII. GLOSSARY

DEPOSITION - MATERIAL THAT SETTLES FROM A FLUID (WATER OR WIND).

EROSION - REMOVAL OF MATERIAL, GENERALLY EARTH MATERIALS.

FAULT - BREAK IN ROCK ALONG WHICH MOVEMENT HAS TAKEN PLACE.

FORMATION - A BODY OF ROCK STRATA, OF INTERMEDIATE RANK (MAPABLE), WHICH IS UNIQUE WITH RESPECT TO ADJACENT STRATA BY CONSISTING DOMINANTLY OF A CERTAIN ROCK TYPE (SANDSTONE, LIMESTONE, ETC.) OR COMBINATION OF TYPES.

JOINT (FRACTURE) - BREAK IN ROCK ALONG WHICH MOVEMENT HAS NOT TAKEN PLACE.

LITHOLOGY - THE DESCRIPTION OF ROCKS, ON THE BASIS OF SUCH CHARACTERISTICS AS MINERALOGIC COMPOSITION, AND GRAIN SIZE.

MINERAL - NATURALLY OCCURRING INORGANIC SUBSTANCE WITH PHYSICAL AND CHEMICAL PROPERTIES THAT VARY WITHIN NARROW LIMITS.

ROCK - AGGREGATE OF ONE OR MORE MINERALS

STRATA - A TABULAR OR SHEETLIKE BODY OR LAYER OF SEDIMENTARY ROCK, VISUALLY SEPARABLE FROM OTHER LAYERS ABOVE AND BELOW.

WEATHERING - PHYSICAL (DISINTEGRATION) AND/OR CHEMICAL (DECOMPOSITION) OF MINERAL/ROCK.

Clandestine Tunnel Operations Historical Perspectives and the Role of Engineering Geology

Dr. Christopher P. Cameron
University of Southern Mississippi

Abstract

Clandestine tunnel construction has a long and varied history. Tunnel construction for military purposes is a well-documented chapter in the history of war. The success of military "mining" in breaching fortified walls and field works during storied ancient and medieval campaigns was followed by several instances of dedicated clandestine tunnel operations during the American Civil War at the "Battle of the Crater" near Petersburg, Virginia, and at Vicksburg, Mississippi. Approximately fifty years later successful covert tunneling operations of the Allies at Sebastopol were followed by huge British victories on the Western Front at the Somme (1916) in France and at Messines Ridge (1917) in Belgium, achieved by detonating up to 600 tons of high explosives in multiple clandestine tunnels and galleries dug beneath enemy lines. During WWII the covert logistic re-supply to a beleaguered Stalingrad was effected through subterranean sewers; and the Axis powers were very efficient in their use of tunnels and large underground space for logistic storage and even manufacturing. The use of very extensive camouflaged clandestine tunnel networks by the Viet Cong in Southeast Asia is also a well-documented case history in underground logistics and re-supply. Finally, a stalemated war in difficult terrain on the Korean Peninsula resulted in widespread tunnel construction by the North Korea People's Army for a variety of reasons including the covert infiltration of agents and armed forces.

Clandestine tunnel operations for concealment and protection of strategic assets, political, espionage, terrorist, and criminal purposes are less well-documented but have been reported on a worldwide basis over a lengthy period of time. Significant penetration of international borders by use of clandestine tunnels has been accomplished by political refugees; for example, to escape "under the wall" from East Berlin. Clandestine tunnels have been used by terrorists to assassinate their political enemies. Criminal elements have also used this method to perpetrate grand theft, drug smuggling, and escape from long-term incarceration.

Engineering geological site characterization, particularly rock mass (or soils) classification and distribution, provides useful input at every phase of clandestine tunnel detection and neutralization including (1) assessment of clandestine tunnel design, degree of construction difficulty, tunnel stability, and support, de-watering, and maintenance requirements, (2) assessment and interpretation of data produced by geophysical, remote sensing, geohydrological surveys, (3) analyses during the discovery and verification phase of tunnel detection, and (4) analyses and documentation during the post-discovery phase.

Discussion

LEA: Are drilling companies required to obtain permits from State and Federal Governments in order to drill?

SCIENTIST: Companies that conduct drilling operations are required to get permits from the respective State and Federal Government to carry out these operations. The locations, depths, and character of the operation, particularly in the United States, are recorded.

SCIENTIST: Why do people still work the tunnels along the DMZ (demilitarized zone)? The initial strategy of the North Koreans was very good when the DMZ was nothing but one thin defensive line. This strategy has changed. Between 1971 and 1991, the Republic of Korea Army went through a massive change in terms of its competencies, equipment, and its nested defenses. The South Koreans want to assume responsibility of tunnel detection for political reasons.

LEA: LEA has been involved in tunnel detection since 1980 and has conducted seismic tests, electromagnetic sensing, and ground penetrating radar (both land bound and air bound) coordinated by BRDEC. We found that if a tunnel is more than 10 ft underground, then it will be extremely difficult to locate.

SCIENTIST: The importance of site characterization is to save time and cost of utilizing certain types of equipment. The reconnaissance phase is conducted by the geologist and sets the stage for the geophysicist to select the most appropriate tools for detecting tunnels.

Clandestine Tunnel Operations

Historical Perspectives

Military Objectives

- Battlefield
  - Penetration of Fixed Defenses
  - Personnel and Materials Storage
- POW Escape
- Political Prisoners and Refugees
- Political Terrorism
  - Assassination
- Criminal Elements
  - Smuggling
    - Materials Storage
  - Grand Theft
  - Escape

Geological Site Characterizations

GOALS

1. Support Tunnel Detection and Neutralization
   Assessement of:
   - Clandestine Tunnel Design
   - Degree of Construction Difficulty
   - Stability
   - Support Requirements
   - Maintenance Requirements

2. Aid Design of Geophysical Surveys

3. Assessment and Interpretation of Surface and Borehole Geophysical Data

4. Assessment and Interpretation of Geohydrological Data

5. Counter-Tunnel Design and Construction

6. Other Neutralization Techniques

Geological Site Characterization

Objectives

1. To Characterize the Geomechnical Behavior of the Rockmass and Develop Estimates of Tunnel Construction Difficulty, Stability, and Support Requirements

2. To Provide Lithological (Mineralogical) and Structural Discontinuity Data Needed to Optimize Interpretation of Surface and Subsurface Geophysical Surveys

3. To Provide a Geological Framework Containing Elements Essential to Interpretation of the Hydrogeological Regime and the Behavior of Groundwater and/or Injected Fluids at Depth

4. To Provide the Framework Data Necessary to Understand the Nature and Possible Extent of Old Mines, Minerals Workings, and Quarries in Target Area

Geological Site Characterizations

Working Hypotheses and Assumptions

1. Complexity of Geological Environments Often a Function of the Overall Age(s) of the Terrane Involved

2. Invariably Most Complicated are Very Old Rocks Lithologically and Tectonically Overprinted by Successively Younger Sedimentary, Metamorphic, and Igneous Events

3. The U.S. - Mexican Border Region is Comprised of Such Terranes - Lithological and Structural Discontinuities Tend to Dominate Regional and Local Geology

4. Engineering Geological Site Characterizations and Site Specific Mining Exploration are Similar:
    - Both Efforts Highlight the Fact that No Two Target Areas, Sites, or Sub-Sites, are Exactly Alike in the Geological Environment

5. Only Those Components of the Geological System of Decisive Significance to Mission Objectives Can Be Mapped and Studied in Detail

Clandestine Tunnel Detection and Neutralization

Selection of Technique

- Intelligence Profile
  - Humint
  - Engineering Intel
- Geological Site Characterization
- Geophysical/Remote Sensing
- Common Sense and Intuition
- Team Approach

Tunnel Detection and Neutralization

Common Sense Techniques

Tunnels Through Earth Materials Possess
Unique Character:

They Have an Absence of Soil or Rock

They Have Elongated "Third" Dimensions

They Often Have "Halos"

They May be Most Easily Found Where Most Easily Made

Their Builders Like to Look Over Them

Record Keeping

The Archives are a Key to a Successful Program

- Intel Files
- GIS Database

Trenchless Technology

Mr. Robert D. Bennett
Waterways Experiment Station

Abstract

Over the past decade, trenchless technology has provided an alternative to traditional open cut construction. Two aspects of this technology, microtunneling and directional drilling, can be utilized in construction of clandestine tunnels. In Japan, where microtunneling originated, its definition generally referred to non-man size entry tunnels less than 900-mm diam. When that technology came to the United States, the definition was broadened to focus more on the method for building these tunnels and not on the size since the same method can be used for driving tunnels from 10-in. diam to 10 ft or larger. Microtunneling is basically a remote controlled, laser-guided pipe jacking operation where the total lining or pipe is installed as the tunnel is driven. The requirement for personnel is minimal. Personnel entry to the tunnel face is not required. The spoil is transported out the back either by an auger system or by a slurry separation system, and the pipe is jacked forward from a jacking station at the entry point. When the tunneling machine exits at its planned point, the installation is complete. There is no need for dewatering or for ground stabilization and, therefore, is difficult to detect. Microtunneling can be used in almost any geological conditions.

The guidance and control systems in directional drilling are usually not as sophisticated in most cases as microtunneling. Directional drilling is a cycle of drilled pilot holes and reaming that hole to achieve the final diameter needed. For large river crossings, steel pipe is welded together in a large staging area on the exit side and then pulled back in one continuous operation. Plastic pipe is used for smaller diameter holes, such as for municipal water, gas, and cable installations. The small diameter rigs are capable of installations of approximately 300 to less than 600 ft in length with diameters of 4 in. to 10 in. There is a higher noise level and other indications of surface activity with directional drilling than with microtunneling.

Discussion

SCIENTIST: What technology level is needed to operate the microtunneling equipment?

SCIENTIST: Microtunneling equipment may by used to place sensors underground for geophysical research eliminating the problems dealing with signal-to-noise ratio of cultural activity. In the United States, there are a limited number of skilled technicians that can operate these machines. Most of the machine manufacturers bring in technicians from the company to train the contractor. At this time, there are five manufacturers marketing machines in the United States: Iseki in San Diego, California, Herrenknecht in Atlanta, Georgia, Soltau in South Carolina, McLaughlin/Markham in South Carolina, and American Augers in Wooster, Ohio. There have been approximately 24 to 28 machines sold in the United States. In Japan, there are over 30 manufacturers with over 1,000 machines in operation. There is no reason one of these machines originating in Japan or Germany could not be used once in a legitimate job and then diverted elsewhere for an illegitimate job.

LEA: Is it necessary to have a shaft on both ends before you employ your microtunnel?

SCIENTIST: An exit shaft is not a requirement for a microtunnel. The machine can be excavated when the tunnel is complete. The units use a 60 to 100 kW generator operating everything, including the computers. The drive units are electrohydraulic. The cost of the equipment would be approximately 1 million dollars. For the most part, microtunnels are constructed in a straight line. A watertight installation is needed and curves may cause the pipe joints to leak or break. There is no requirement for straight drives with directional drilling; any reasonable curved path can be constructed. Neither entry nor exit shafts are required for directional drilling. These systems are surface-launched.

LEA: If wires are not placed in the pipe, then some of the geophysical techniques that are currently used to detect tunnels would be useless.

SCIENTIST: Detection might still be possible if fluid is moving through the ground that is not natural to the area.

SCIENTIST: During the 1980's, WES did a great deal of work for the Ballistic Missile Office involving development of sensors that could locate underground tunnel boring machines.

SCIENTIST (Summary on Microtunneling): Microtunneling could be successfully used under any geological conditions to construct tunnels up to 1 mile or more in length, from 10 in. to 10 ft in diameter, with minimal surface activities, with minimal crew requirements, and in a short time. Tunneling activities could be easily disguised by setting up a sand and gravel or concrete plant on one side or the other of the planned crossing. This would minimize any suspicions related to muck transport, disposal, pipe purchase, and delivery. Pipe could be manufactured on site. Personnel entry into the tunnel is not required for construction, so security risks would be low. Pipe materials do not necessarily contain any metal, so detection by magnetic means would be impossible. Transportation of contraband could be accomplished robotically, again minimizing security risks and large diameter requirements. Perhaps as few as four people could run the smuggling operation. For detection,

observation of surface activities could be severely impaired by simple means, as noted above. Since so few personnel are required to construct or operate the facility, chances for infiltration or turning an informer would seem low. Traditional geophysical means of detecting the tunnels may be unproductive, because the diameter to depth ratio can be very small, and because the pipe materials can be nonmagnetic or provide poor signal definition. Dust and noise are low, further hampering detection during construction.

Perhaps a more promising approach is to track the manufacture, sale, lease, use, and/or transport of tunneling machines. At present only about two dozen machines have been sold in the United States and there are only two United States manufacturers. One Japanese and two German manufacturers market their machines in North America. However, over 30 companies, mostly Japanese and German firms, manufacture machines and over 1000 machines exist in Japan alone.

SCIENTIST (Summary on Directional Drilling): The smaller-diameter less expensive directional drilling rigs are typically limited to drives of 1000 ft or less, and diameters of 16 in. or less, due to limitations on torque and thrust capabilities. The larger rigs can install pipelines from 8 in. to 84 in. for runs of up to one mile or more, though 1/2 mile is more typical. Accuracy is not as good as microtunneling and costs and crew requirements are similar for the larger rigs. Large layout areas are typically required to allow the steel pipeline to be laid out and welded together prior to the continuous pullback operation. This surface activity could be disguised but not very easily. Since the costs, crew, and skill requirements are similar to microtunneling, and the required accuracy and concealment are not as easily achieved, it is more problematic, but not impossible to use large diameter directional drilling for constructing crossings within the length and diameter ranges necessary.

MICROTUNNELING DEFINITION

- LASER-GUIDED
- REMOTELY-CONTROLLED (PERSONNEL ENTRY NOT REQ'D)
- PIPE JACKING

MICROTUNNELING CAPABILITIES & CHARACTERISTICS

- TUNNEL LENGTH: 1/4 MILE - ROUTINE

  1 MILE + - FEASIBLE BUT GUIDANCE SYSTEM (LASER) IMPROVEMENTS NECESSARY

- TUNNEL DIAMETER: 10 INCH TO 10 FT + (BUT FOR LONG TUNNELS, DIAM $\geq$ 36" PRESENTLY REQUIRED FOR INSTALLATION AND REMOVAL OF INTER-JACK STATIONS

- ACCURACY: $\pm$1 INCH FOR LINE & GRADE

- DEPTH: 3 FT TO 100 FT OR MORE

- GEOLOGY: -CAN INSTALL PIPE THROUGH WIDELY VARYING GEOLOGIC CONDITIONS, INCLUDING ROCK, MIXED GROUND, SAND, SILT AND CLAY ABOVE OR UP TO 100 FT BELOW WATERTABLE
  - -CLEAN WATERBEARING GRAVELS PRESENT PROBLEMS
  - -CAN HANDLE OCCASIONAL BOULDERS, COBBLES UP TO $\approx$ 1/3 DIAM OF FACE
  - -GROUND STABILIZATION OR DEWATERING NOT REQUIRED

- MINIMUM SHAFT SIZE: 8 FT DIAM
- SURFACE ACTIVITIES/FOOTPRINT: MINIMAL, APP. 2,000 FT^2
- ADVANCE RATES: 60 FT/DAY TYPICAL $\geq$ 200 FT/DAY OCCASIONALLY
- CREW REQUIREMENTS: 3-6, INCLUDING 1 SKILLED OPERATOR, 2-5 UNSKILLED LABORERS

- PIPE: -CONCRETE

  -HOBAS (GRP)

  -STEEL

  -VITRIFIED CLAY

  -PVC - IN SPECIAL CASES ONLY

-PIPE IS INSTALLED AS TUNNEL IS DRIVEN

- LOW NOISE, DUST, OTHER INDICATIONS OF ACTIVITY
- CAPITAL COSTS LESS THAN $1 MILLION
- PIPE COSTS - INSTALLED, APP $500/FT FOR 36 INCH DIAM

DIRECTIONAL DRILLING CAPABILITES & CHARACTERISTICS

- GUIDANCE & CONTROL NOT AS SOPHISTICATED AS FOR MICROTUNNELING BUT STEADILY IMPROVING
- REMOTELY CONTROLLED
- DRILL, REAM, PULLBACK PIPE SEQUENCE OF OPERATIONS

- LENGTHS: 400 TO 2,000 FT TYPICAL 1 MILE OR MORE POSSIBLE
- DIAMETER: 4 INCHES TO 7 FT
- ACCURACY: 5% OF LENGTH FOR LINE AND GRADE CONTROL
- DEPTH: NO CONSTRAINTS
- GEOLOGY: NO CONSTRAINTS
- SHAFTS: NOT REQUIRED

- SURFACE ACTIVITIES/FOOTPRINT: INCREASES WITH LENGTH AND DIAMETER OF CROSSING

  APP 400 FT^2 FOR SMALL DIAMETER, SHORT DRIVES

  LARGE STAGING AREA TRADITIONALLY REQUIRED FOR LARGE CROSSINGS

- ADVANCE RATES: 300 FT/DAY FOR DRILLING & REAMING TYPICAL
  2 DAYS OR LESS FOR PULLBACK TYPICAL

- CREW REQUIREMENTS:
  2-10, INCLUDED 1 SKILLED OPERATOR

- PIPE: -STEEL TYPICALLY FOR LARGE DIAMETER CROSSINGS
  -PLASTIC FOR SMALL DIAMETER, SHORT CROSSINGS

- HIGHER NOISE, OTHER INDICATIONS OF ACTIVITY, COMPARED TO MICROTUNNELING BUT LITTLE DUST
- CAPITAL COSTS: $40,000 TO $1 MILLION
- PIPE COSTS: INSTALLED, APP $500/FT FOR 36 INCH DIAM

Tunnel Detection: History and Basic Concepts

Dr. Dwain K. Butler
Waterways Experiment Station

Abstract

Despite decades of effort and technology advance, detection and delineation of subsurface cavities, tunnels and mines remain the most difficult class of problems addressed by engineering geophysics. As geophysical technology has advanced, so have the difficulties of the geotechnical problem requirements. Three primary application areas are drivers for development of geophysical technology for cavity and tunnel detection: (1) offensive and defensive military considerations; (2) civilian geotechnical considerations; (3) civilian criminal activities or law enforcement considerations. These drivers have all contributed to development of geophysical technology for detection of subsurface anomalies. Detection of these anomalies, such as cavities and tunnels, is dependent on background complication and size of the feature. The anomaly caused by the void space is due to the contrast with surrounding geological material and its characteristics. Anomalies also result from secondary effects around the tunnel or void caused by stress redistribution, cracking, and groundwater flow. Stress redistribution is independent of the type of construction and can occur in any geologic environment. Materials within the tunnel may also contribute to an anomaly.

Detection and characterization of any anomaly are determined by magnitude, effective diameter and depth, and noise. Detectability is also dependent on sensitivity and accuracy of the measurement system and its depth of investigation. Tunnel detection methods are divided into active or passive methods. In using an active method, the energy must be supplied; whereas a passive method is used to measure the effects of a source already present.

Discussion

LEA: In Otay Mesa, the only technique that seemed to have worked was seismic. Ground penetrating radar and various other methods were tried, but were not successful.

SCIENTIST: Probably the most successful method used at Otay Mesa was an electromagnetic method. Gravity was the one technique that was not tried. It should have been the first one used. It is site dependent, but the type of soil or rock does not matter. There is always a deficiency of mass that is represented by a cavity or tunnel. The deficiency cannot be directly masked. There are ways that nature can mask it, but the deficiency is always there.

SCIENTIST: A key difference between the resistivity survey and the electromagnetic induction method (EIM) is that the resistivity survey requires physical contact with the earth; whereas the latter does not require physical contact. For the EIM, the receiver can be virtually anywhere as long as it is close to the earth. Typically, spacing between the two outer electrodes for the resistivity needs to be about five times the desired depth of investigation. If there is a tunnel 50 ft deep, there needs to be 200-250 ft between the outer two electrodes. There will very likely be a number of measurements made on the surface above the tunnels with that same spacing. If you want to investigate to a different depth, then another set of measurements must be made. The presence of anything additional, such as metallic material in the tunnel, is a plus but not necessary with resistivity surveys. For EIM, sensors at the surface can have a coil and a magnetometer. The key variable is the spacing and also the frequency being emitted. The size of the coil is not necessarily a variable.

LEA: What about timeliness of monitoring the sensors for EM surveillance? Is that something that is recorded in some type of device that can be retrieved after a week, or is it something that is time sensitive that can be remotely monitored?

SCIENTIST: If you're looking at just monitoring for activity within the tunnel, this can be remotely monitored with no problem. The EM data can be recorded on a data logger for later retrieval. There is a fundamental difference between trying to detect the tunnel and monitoring for activity within the tunnel.

SCIENTIST: There are some automated pieces of electrical resistivity systems available where you can install a large number of electrodes and automatically switch between them. One can then go back and forth and select sets of four electrodes on an array of electrodes. This approach allows more or less permanent monitoring. One has the option of switching between them to continually investigate a wide variety of depths.

SCIENTIST: This was actually done in the mid-1970's at a cavity test site using an automated electric resistivity surveying system. An array of electrodes was set and swept through all possible combinations automatically. This hardware can be left in place as a monitoring tool.

SCIENTIST: Another system developed by the Navy is electromagnetic, having a transmitter at one end and a receiver at the other end. This system is currently being used to map structures on the bottoms of rivers and is supported by a small barge or a float. The system can be considered portable. It has been used on the surface but not underground. The difference between this

system and others used in conventional surveying operations is that this is a digital device that can output as many frequencies at the same time as you want to program into it. The tube is 22 ft long and about 18 in. in diameter. The frequencies used can be as low as 100 Hz or as high as few tens of kHz. It was originally designed as an airborne system.

LEA: What size objects were you looking for in the river?

SCIENTIST: On the river, we were looking for what is called articulated concrete mattress that is used to stabilize the streambank to prevent erosion. These mattresses are predominantly concrete, but they have a wire fabric running through them. The target was the wire fabric. It is a very small amount of wire but it is a phenomenal electrical target.

LEA: The Otay Mesa is an ideal situation. The owners of the property where the tunnel is located have agreed to keep it open until we are through testing. The site has lights inside and other mechanical equipment that could easily be detected.

LEA: Given advanced technology, are there any cases where tunnels were actually detected?

SCIENTIST: There has been success in the civil sector such as locating underground workings.

History of Tunnel Detection and Emergence of Geophysical Technology

Tunneling and Utilization of Existing Cavities and Tunnels have Played Important Roles in Conflicts Throughout History

- Logistics and Storage
- Troop Insertions behind Enemy Lines and Across "Secure" Borders
- Intelligence and Covert Operations
- Terrorism
- Demolition
- Access to Secure Installations
- Safe Refuge

Tunneling is a Method of Consideration for Criminal Activities Such as Smuggling, Prison Excape, and Robbery

Both Military and Civilian Requirements have been Drivers for Development of Geophysical Technology for Cavity and Tunnel Detection

Tunnel Detection Problems/Programs

1960's
- Tunnels in Viet Nam
- Cavities in Karst Regions

1970's
- Cavities in Karst Regions
  - DOT/FHWA Cavity Detection Program
  - COE/WES Cavity Detection Program
- Korean Intrusion Tunnels Discovered
  - DARPA Tunnel Detection Program

1980's
- Cavities in Karst Regions
  - COE/WES Cavity Detection Program
- Korean Intrusion Tunnels
  - MRADCOM/BRDEC/WES Tunnel Detection Program
- Deep Basing of Missiles and other Military Facilities
  - AF-BMO Tunnel/Tunneling Detection Program
  - DNA Program
- Interagency Coordinating Group on Geophysics Formed

1990's
- Drug Smuggling Tunnels
  - CD RDA Tunnel Detection Program
- Underground-Based Military Assets

CAVITIES AND TUNNELS

Natural

Underground Caves, Tubes, Chambers, Pipes, etc., Formed by ***Natural Processes***

Frequently Formed in Limestones

May be --
- Air-filled
- Water-filled
- Soft sediment-filled
- Partially filled

Man-Made

Mines -- Shafts, Tunnels, and Chambers
- Known: Active Mines
- Unknown: Abandoned (Records Lost); Ancient (with Trivial Surface Expression)

Tunnels --
- Known: Railway, Highway, Sewer, etc.
- Unknown: Covert, Intrusion, Abandoned

May be Lined or Unlined --
- Dependent on Soil or Rock Type and Condition
- Complete or Partial
- Wood, Concrete, Steel, PVC

May be All or Partially Water-Filled

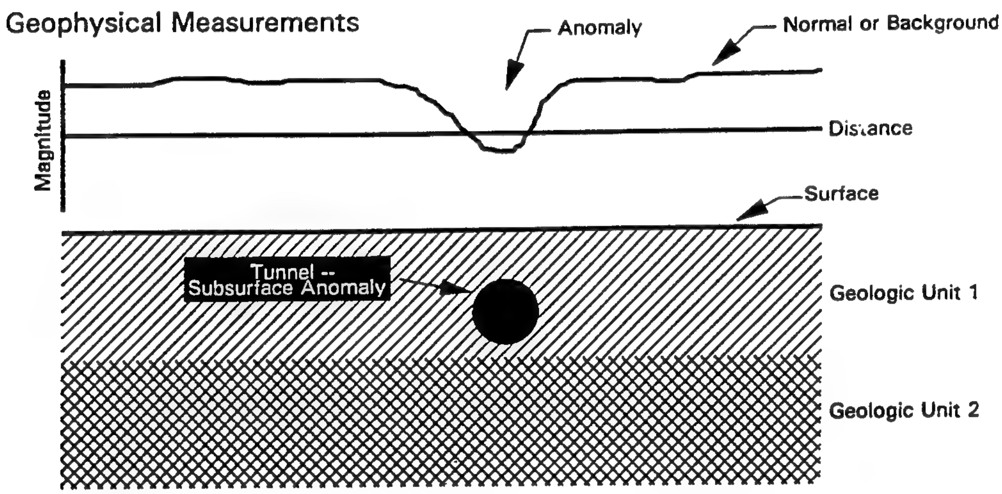
May Contain --
- Rails
- Power Lines
- Ventillation Pipes and Shafts
- Pumps and Other Motors
- Other Metallic Objects

Anomalies Caused by Cavities and Tunnels

Definitions

In the subsurface, an ANOMALY is a departure from normal or background conditions. Can be a natural or man-made anomaly, such as a tunnel.

On the surface, geophysical methods measure or detect an ANOMALY or anomalous signature caused by the subsurface anomaly.



Anomalies caused by *Void Space*

- Density anomaly
- Seismic velocity anomaly
- Electromagnetic velocity anomaly
- Electrical resistivity anomaly
- Anomalies in other electromagnetic properties

Anomalies caused by secondary effects around the tunnel

- Stress redistribution
- Cracking and fracturing
- Subsidence
- Induced ground water flow

Anomalies caused by materials within the tunnel

- Water
- Tunnel lining
- Metal
- *Noise*

WHAT DETERMINES IF A CAVITY OR TUNNEL CAN BE DETECTED ON THE SURFACE ?

Magnitude of the Anomaly
- *Size*
- *Depth*
- *Contrast*

Noise
- *Manmade or Cultural*
- *Natural*

Sensitivity and Accuracy of Measurement System

Depth of Investigation of Measurement System

Classifications of Tunnel Detection Methods

Source	*Active and Passive*
Location	*Airborne, Surface and Subsurface*
Physical Principal	*Seismic (Mechanical) Wave Propagation* *Electromagnetic wave propagation* *Electrical current propagation* *Electromagnetic induction* *Potential fields (gravity and magnetic)* *Heat flow* *Direct contact – Drilling and penetrometers*

Seismic Methods

Passive

Applications

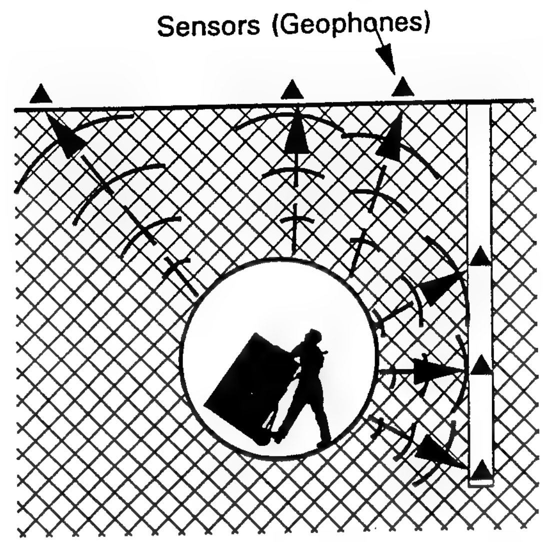
Tunnel location -- "Triangulation"
Activity monitoring

Requires only Sensors

At surface or within boreholes

Sources -- Within tunnel

Vehicles
Walking
Motors
Active tunneling

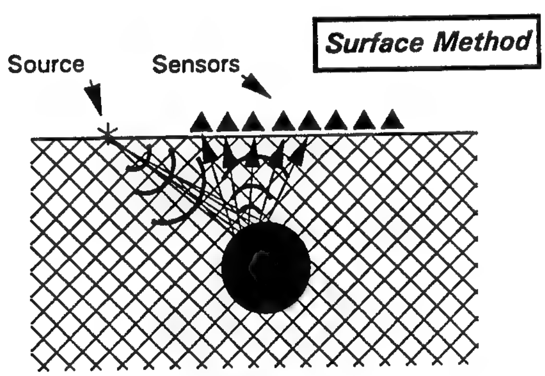


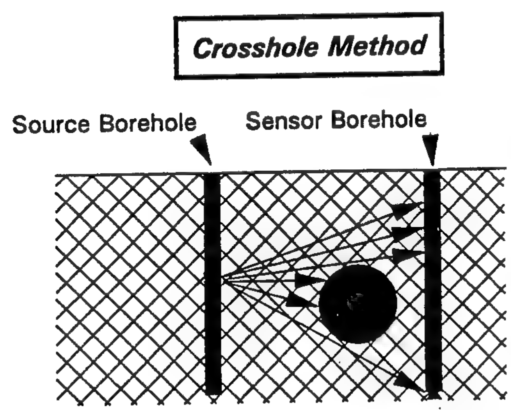
Active

Requires both Source and Sensors

Surface and Borehole

Application -- Tunnel Location





Concepts of the Geophysical Methods

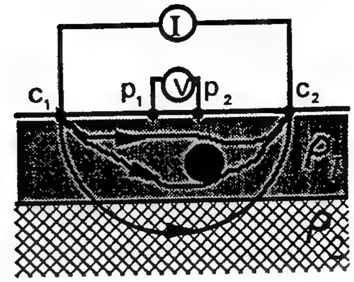
Electrical and Electromagnetic Methods

Passive

Application -- Detection of and Monitoring for Electromagnetic Signals from Tunnels

Requires --
- Surface Electrodes
- Magnetometers
- Wire Loops
- Receiver Electronics

Electrical Resistivity Method



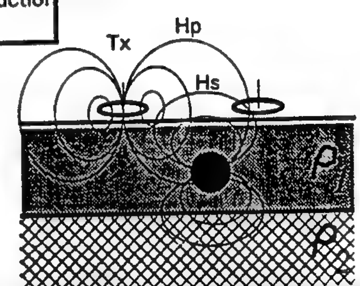
Active

Application -- Detection of Tunnels

Requires --
- Surface Electrodes
- Magnetometers
- Wire Loops
- Transmitters
- Receivers

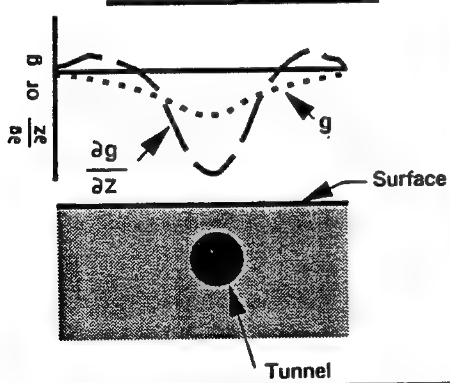
Types --
- Electrical Resistivity
- Electromagnetic Induction
- Ground Penetrating Radar

Electromagnetic Induction Method



Gravimetry and Gravity Gradiometry for Tunnel Detection

Anomaly Signature



Gravimetry

- Relatively Simple and Reliable Technology; Slow
- Tunnels Detectable to Depth Equal to 10 x Tunnel Diameter

  Ex.-- 2 meter diameter tunnel can be detected to depth of 20 meters
  (Assuming 5 microgal gravity measurement accuracy)

Gravity Gradiometry

- Complex Technology; Possibility for Rapid, Potentially Covert Deployment
- Higher Resolution than Gravity

  Ex.-- 2 meter diameter detectable to depths < 25 meters
  (Assuming 1-2 Eotvos gravity gradient measurement accuracy)

Two Gravity Gradiometer Systems for Tunnel Detection Consideration

BELL AEROSPACE
GRAVITY GRADIOMETER SURVEY SYSTEM (GGSS)

Concept: Pendulum, Force Feedback Balance, Accelerometers on Moving Base

Status: Operational; Field Tested

Theoretical Sensitivity: 0.01 Eotvos

Operational Accuracy: 5-10 Eotvos

Advantages: Operational; On-Going Applications; Proven Technology

Disadvantage: Complex System Mechanically and Electronically; Physically Large

JOHNS HOPKINS APPLIED PHYSICS LABORATORY
GRAVITY GRADIOMETER

Concept: Spring/Mass Accelerometers, Differential Displacement, Fixed Base

Status: Laboratory Prototype

Theoretical Sensitivity: 0.01 Eotvos

Operational Accuracy: Not Established

Advantages: Potentially Higher Accuracy; Less Complex; Smaller

Disadvantage: Still Prototype; Not Field Tested

History of Tunnel Detection and Emergence of Geophysical Technology

Tunnel Detection and Geophysical Technology -- The 1960's

Geophysical Methods --

- Seismic Refraction and Attenuation
- Electrical Resistivity
- Fluxgate Magnetometers
- Airborne Photography and Infrared Imagery
- Gravity
- Research on High Frequency Radio-Wave Methods

Key WES Publications --

1967 -- "...Very High Frequency Radio Imaging Techniques for Detection of Tunnels", TR 3-769

1967 -- "Environmental Characteristics of Tunnels in South Vietnam", MP 4-919

1968 -- "WES Tunnel Explorer Locator System", IM

The 1970's

Geophysical Methods --

Microgravimetry Developed
High Resolution Seismic Reflection
New EM Methods Developed
Crosshole Seismic and EM Methods Developed
Proton Precession Magnetometers

Key Publications and Events --

1973 -- "Detection of Subsurface Cavities", MP S-73-40

1975 -- Development of WES Cavity Detection Test Facility (1980 -- WES TR GL-80-4)

1977 -- International Symposium on Detection of Subsurface Cavities (1977 -- WES "Proceedings....")

The 1980's

Geophysical Methods --

Magnetic Gradiometers
Borehole Gravimeters
Geotomographic Methods
Ready Availability of Field Computers and Data Acquisition Systems
Ground Penetrating Radar; PEMS
Gravity Gradiometers (Military Gradiometer Program)

Key Publications and Events --

1982 -- "Tunnel Detection", WES TR GL-82-9
1983 -- "Detection and Delineation of Subsurface Cavities", Reports 1-5, WES TR GL-83-1
1984 -- "Microgravimetric and Gravity Gradient Techniques for Detection of Subsurface Cavities", Geophysics, July 1984
1984 -- "Active Detection of Tunnels by Induced Seismic Spectra", WES MP GL-84-18
1988 -- "Detection of Tunnels by Transient Electromagnetic Subsurface Imaging", WES Final Report (Feb. 1988)
Field Experiments for Detection of TBM's, Throughout U.S., 1984-88
Field Investigations for Detection of Korean Intrusion Tunnels

The 1990's

Geophysical Technology --

Maturation of Airborne Geophysical Surveying
Integration of Geophysical Surveying and Automated Positioning
Integrated Inversion of Multiple Geophysical Datasets
Surface and Airborne Gravity Gradiometry
Digital Multifrequency EM Systems
Virtually Continuous Surface and Airborne Measurements

Key Publications and Events --

1991 -- "Repeat Gravity Surveys for Anomaly Detection in an Urban Environment", Proceedings of 1991 SEG Meeting
1990, 1993 -- Drug Smuggling Tunnels Discovered, Southwest U.S. Border

TUNNEL DETECTION

Future Research, Development and Applications Thrusts

RECOMMENDATIONS

General --

- Develop Low Observable/Covert, Rapid Geophysical Surveying Methods
- Develop Tunnel Detection R&D Facility (Testbed)
- Surface Methods Field Tests ---▶ Airborne Evaluation
- Assess Feasibility of Large Scale Reconnaissance Surveying of Entire U.S.-Mexico Border and Periodic Monitoring
- Consider High Risk/High Payoff Research -- "Star Wars Approaches"

Specific --

- Assess Potential Role of Airborne/Satellite Multispectral Imagery
- Develop Innovative Active Profiling Methods
- Develop and Evaluate Tensor Magnetometer
- Develop and Evaluate Gravity Gradiometer
- Evaluate Navy Digital Multifrequency Electromagnetic System

MINI-PANEL DISCUSSION

Purpose

The purpose of the mini-panel discussion was to provide WES scientists with information on tunnel sites and to discuss realistic site conditions. Location priority of suspected tunnel locations was needed to construct a site reconnaissance plan and select the optimum geophysical method and equipment. Pertinent facts from three major topic areas are summarized below.

Panel Members:
Larry Caver, U.S. Border Patrol
Rich Gorman, Drug Enforcement Administration

Property Ownership

The Federal Government (i.e., Border Patrol) does not have a continuous easement along the southwest border. There is some property along the border, such as in El Paso and the Big Bend country, that is owned by the Government. There have been problems with people having dual citizenship owning property on both sides of the border. In the past, some of these people have been involved in illegal activities across the border for many years. A buffer zone providing general access to the public does not exist along the border; the only exception being a fence line in Texas referred to as the "tick line". Two fences running parallel are separated by a distance of approximately 15 ft. Otherwise, private property lines extend to the border edge. In San Diego, California, there is a border fence approximately 12 ft high with a 30 ft easement extending north from the fence. The Border Patrol uses this area to patrol for illegal aliens.

Tunnel Locations

Both tunnels that have been discovered were in urban environments: Otay Mesa, California, and Douglas, Arizona. Otay Mesa is one of the largest commercial points of entry with several thousand trucks per day passing through the entry. There are several factors that made this area a prime location for subsurface activity. Because of rapid acceleration in construction

activity in this area, the building of new facilities and presence of construction equipment were not questioned. High urban traffic acted as concealment for tunneling activity. Major industrial growth is apparent on both the north and south sides of the border. Otay Mesa also provides a main access route to Los Angeles, California, Tijuana, Mexico, and the Baja Peninsula. The tunnel at Otay Mesa was 65 ft deep on the south side and 35 ft deep on the north side. Aerial photography reviewed after the tunnel discovery revealed the presence of a nearby gravel pit, spoil piles that were very obvious, and a path that had been worn by trucks going across the ground to dispose of spoils. The tunnel in Douglas, Arizona, was not discussed.

Description of Otay Mesa Tunnel Site

The tunnel originated in an abandoned used car lot on the Mexican side of the border. A fence 20 to 40 ft high was built around the property so that no one could see inside this location. A ramp area was constructed so that a dump truck could be backed into the area to collect tunnel spoils. The truck would then drive across the road and deposit the spoils in a nearby quarry. A hole was cut in the floor of the building to enter a subterranean room. In a separate room, four air compressors were connected in series to run pneumatic hammers. Construction of the tunnel probably began in June or July of 1992, and operations ceased around February 1993. The tunnel was never completed. Approximately 60 ft remained uncompleted, probably awaiting completion of the building where the tunnel would exit.

Geophysical Techniques Applied to Tunnel Detection, Southwest Border

Mr. Donald E. Yule
Waterways Experiment Station

Abstract

Beginning in 1990, geophysical techniques for tunnel detection along the southwest border have been an area of research and have also been utilized in search operations. Although the known tunnels were detectable using geophysical methods, no additional tunnels have been detected at other suspected sites. The two known tunnels were used as test beds to evaluate geophysical techniques. The Otay Mesa, California, tunnel site was evaluated with a suite of seismic, electrical, electromagnetic (EM), and magnetic methods. The effectiveness of the various methods was controlled by site conditions and tunnel features. For the Otay Mesa site, the seismic, electrical, and EM techniques were successful to varying degrees. As a result of these studies, a recommended strategy was developed for application of geophysical methods to future tunnel detection efforts. The proposed strategy is based on sites being selected on intelligence information with high resolution geophysical methods deployed to locate and confirm their existence. After evaluation of site conditions, cultural and geologic, an integrated approach consisting of methods that would be effective would then be conducted to identify anomalies indicative of a tunnel. It is recommended that additional tests be conducted at the Otay Mesa site to evaluate other promising methods and equipment modifications based upon the results of previous tests. It is also recommended that a strategy and a method be developed for selecting and applying geophysical techniques based upon site conditions, target features, and operational and tactical needs.

Discussion

LEA: The Otay Mesa tunnel had not been completed when it was discovered. Operations had ceased for awhile and it was suspected that it was pending completion of the warehouse on the north side of the border. After the tunnel had been located, BRDEC did some of the boring adjacent to the tunnel and did some boring within 2 ft of the

tunnel. The equipment they were using even at 2 ft was not detecting the tunnel. It took a great deal of tuning of that equipment to get it to even give them a satisfactory reading. Ultimately, it did detect the tunnel. It is unlikely the equipment would have been tuned to read the tunnel if it was not known that a tunnel existed.

SCIENTIST: There are a lot of factors in how you apply geophysical techniques. A certain technique should work theoretically, but it's the application or the parameters in the equipment that can defeat the purpose. Passive monitoring can be a successful technique if it can distinguish signals coming from the target and background noise coming from unwanted sources.

In the case of the Otay Mesa investigation, four products are deliverable by September of 1994. One of those techniques is 3-D reflection seismic. In this particular case, one saturates the ground with geophones over and around the tunnel complex. Then points of impact are applied at every one of these geophone stations to produce a 3-D reflection view of the tunnel.

LEA: If you cannot get a repeatable process in all environments, then the system is unreliable.

SCIENTIST: There are exceptions to that statement. For example, ground probing radar operates quite well in non-conducting materials. If you put that same system in a highly conductive environment such as the one at Otay Mesa, it will not work at all. That does not mean that the system will not work. It must be determined under what conditions it will or will not work. A search strategy should combine a variety of techniques so that if one fails then possibly another will succeed. There is a need to have complementary techniques that can be integrated to predict a final answer.

LEA: Boreholes were drilled about 150 ft east and 150 ft west to listen to impulsive noise. The electrical current was hooked and activity was generated in the tunnel to record the response.

SCIENTIST: As a result, all test evaluation guidelines were set by JTF-6 for future tunnel operations to include that the LEAs have hard intelligence confirming tunnel presence and agree to overt operations or recommendations that they do not use these techniques until they mature.

LEA: For law enforcement to get WES to confirm or deny any presence of a tunnel, there are criteria that DOD needs as active and/or reserved forces. The channel of control for LEA's making a request and getting a response would be to notify Operation Alliance.

LEA: What kind of distance between boreholes is possible and still actually get a reading? With boreholes 100 ft apart, did you get a reading?

SCIENTIST: In crosshole seismic work, a lot depends on the seismic source because that has to produce a wavelength compatible with target size. A frequency as high as possible is needed; the trade-off then being the distance that signals can be transmitted. The seismic source used at Otay Mesa may have been the Bureau of Reclamation system operating in the kHz range (four-, five-, six thousand Hz range). The transmission would not be very far, but the resolution would be fairly high. The particular system was a prototype in action without any filtering, and it's more or less raw data. Proper filtering is needed. Borehole spacing should be no more than 50 ft, considering wavelengths for the size target that is suspected. In order to be able to see that target, a seismic source would have to generate frequencies probably in the hundreds of Hz or maybe no more than one kHz to transmit the distance and still produce the resolution.

LEA: Initially, in all cases operation must be as covert as possible. Once all of the covert possibilities have been exhausted, then the option is to go overt.

SOUTHWEST BORDER OPERATIONS

OPERATION

- *Search Using a Suite of Geophysical Techniques*

Douglas, AZ	*4-90*	*Tunnel Located*
Douglas, AZ	*6-90*	*None*
San Luis, AZ	*1-91*	*None*
Calexico, CA	*1-91*	*One Target Located*
Otay Mesa, CA	*3-91*	*One Target Located*
Rio Grande City, TX	*5-91*	*None*

- *Research and Development*

Otay Mesa, CA	*8-93*	*Tunnel Located*

TUNNEL DETECTION
OTAY MESA, CA *(1993)*

► *OBJECTIVES*

- *Operational and Engineering Analysis*
  - *Engineering and Construction*
  - *Excavation Rate*
  - *Debris Removal*
  - *Utilities (Electrical, ventilation)*
- *Evaluation of Geophysical Techniques*
  - *Electromagnetic (EM)*
  - *Seismic*
  - *Electrical*
  - *Magnetic*

Site Conditions and Target Features

- Electrically conductive unsaturated volcanic rock
- Tunnel
  - In soft rock
  - Depth 40-50 ft (uncompleted)
  - 4 x 5 x 1400 ft (W/H/L)
  - Construction
    - Pneumatic tools (chipping)
    - Mostly unsupported construction, one section shored and supported
    - Floor and some wall sections unreinforced concrete lined
    - Utilities: lights, forced ventilation, compressed air line
    - Small rubber tire cart
  - Exploitable features for detection
    - Void (seismic, electrical: material property contrasts)
    - Electrical conductors
    - Monitoring construction / use activities

OBJECTIVE

- ***Evaluate Existing Geophysical Techniques for Tunnel Detection***

  1. ***Detection***
  2. ***Rank Effectiveness***
  3. ***Covert ?***

- ***Results***

  1. ***Yes***
  2. ***Site Dependent***
  3. ***No***

RECOMMENDATIONS (JTF-6)

Detection and Exploitation Methodology

1. *Intelligence to Identify Area of Interest*
2. *Site Survey to Evaluate Site Search Constraints*
3. *Select Geophysical Method(s)*
4. *Apply Method(s) and Interpret Data*
5. *If Targets Are Detected, Confirm Using Further Tests*
6. *Plan and Conduct Tunnel Exploitation and Neutralization Operations*

Recommendations

- Perform additional tests at Otay Mesa
  - High resolution gravity and resistivity
  - Retest of modified equipment for promising techniques
- Develop strategy / methodology for selection and application of geophysical techniques for tunnel detection
  - Factors:
    - Site conditions
    - Target features
    - Operational / tactical needs

Results

- Successful but results driven by specific conditions and target features
- Seismic
  - Surface seismic refraction / reflection . . . Successful
  - Crosshole tomography . . . . Marginal
  - Passive monitoring . . . . Successful
- Electromagnetic (EM)
  - TDEM . . . . Marginal
  - FDEM . . . . Successful
  - GPR . . . . Unsuccessful
- Magnetic . . . . Unsuccessful
- Electrical resistivity . . . . Marginal

RECOMMENDATIONS *(JTF-6)*

FOR FUTURE TUNNEL OPERATIONS

Conditions

1. *"Hard Intelligence" from LEAs confirming tunnel presence*
2. *Right of Entry Established*
3. *LEAs Agree to Overt Operations*

Or

Use of Geophysical Search Techniques Should be Deferred Until Technology "Matures"

Geologic Criteria for Tunnel Detection

Ms. Maureen K. Corcoran
Waterways Experiment Station

Abstract

The geologic criteria include a screening criteria encompassing a generalized study of a specified area. Based on conclusions of that study, the area will be prioritized and a site-specific investigation conducted. There are many different levels for sources of data: state and federal agencies, universities, newspapers, private industry, and public libraries. Data will be in the form of reports, maps, aerial photography, and spot imagery to better assess the geotechnical and geophysical aspects of an area. The geological applications will include both subsurface and surface features to determine the geologic influence on the tunnel. This information will not only have an effect on interior features to surface features but will also affect performance of geophysical equipment. Earth resource data must be analyzed on an individual basis. A geophysical investigation is not only influenced by geology and geomorphology but by soils and groundwater as well. Information obtained from the geological investigation will be incorporated into a Geographic Information System (GIS) to better analyze a site.

Discussion

LEA: In order to conduct a geological survey to determine what type of rock is underneath the ground, what kind of testing is needed? How overt or covert is it?

SCIENTIST: Before we even go into an area like Otay Mesa, we will already have geologic maps and soil maps so we will know what type of formations we should encounter. Well borings will help determine the lithology of the area and the type rock that we're dealing with in the subsurface. On the geologic maps, we'll also be able to determine structure.

LEA: What about locating underground rivers and other such features?

SCIENTIST: Mapping is done from water well borings and aerial photography and can be used to locate abandoned channels and other geomorphic features.

SCIENTIST: Private engineering companies also provide geotechnical and geological information that can be used to characterize a site.

Recommendations

- Perform additional tests at Otay Mesa
  - High resolution gravity and resistivity
  - Retest of modified equipment for promising techniques
- Develop strategy / methodology for selection and application of geophysical techniques for tunnel detection
  - Factors:
    - Site conditions
    - Target features
    - Operational / tactical needs

Future Project Goals

- Review literature
- Construct a Geological Information Database (GID)
- Incorporate information into a GIS
- Site visits to Douglas, Arizona
  Otay Mesa, California
  El Paso, Texas
- Field investigations

Screening Criteria

- General
- Specific

Geologic Applications

- Subsurface
- Surface

Sources Of Data

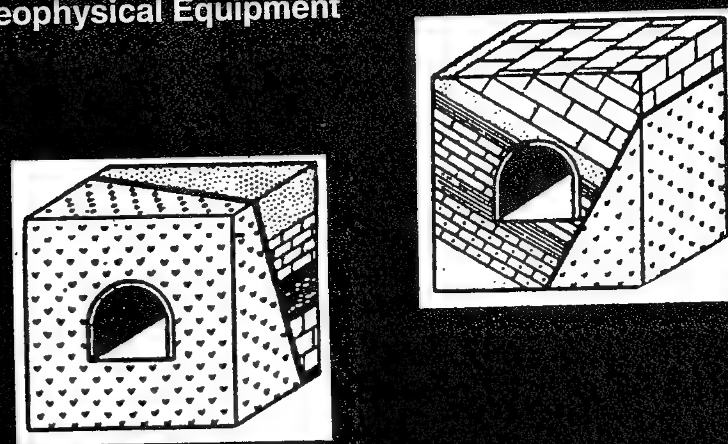
- Local, state, federal agencies
  - State Geological Surveys, Soil Conservation Service
  - USGS, NASA, FBI, DEA
  - Universities
  - Libraries
  - Newspapers
- Private industry
  - Mapping & surveying
  - Photography & imagery
  - Geotechnical
  - Geophysical

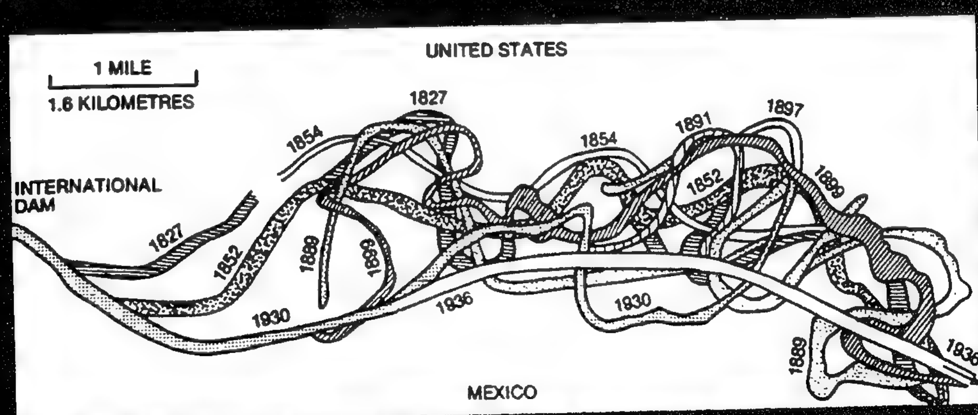
Types Of Earth Resource Data

- Geology / Geomorphology
- Soils
- Groundwater
- Topography
- Mining
- Utilities
- Geophysical
- Vegetation
- Transportation
- Aerial Photography / Imagery
- Real Estate

GEOLOGY/GEOMORPHOLOGY

- Alignment of tunnel
- Interior features to surface
- Geophysical Equipment

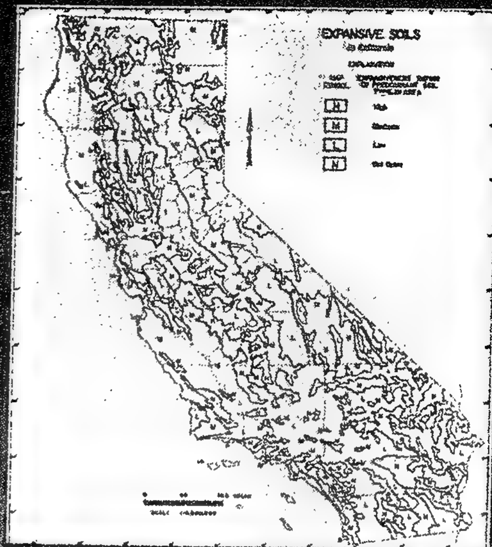




Shifting channel of Rio Grande near El Paso.

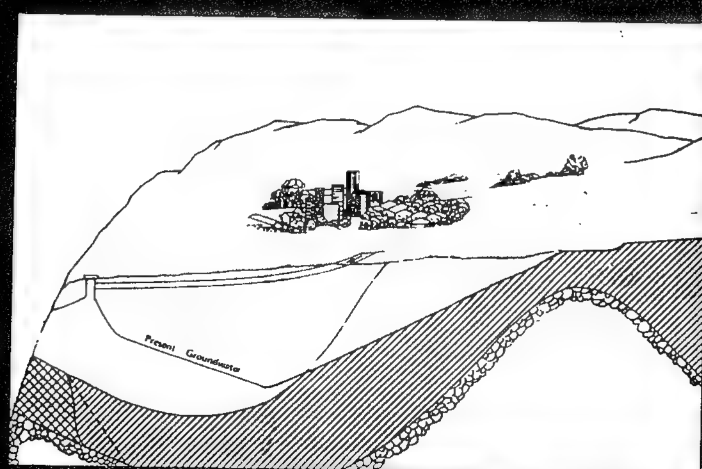
SOILS

- Affect Geophysical Measurements
- Moisture and Density
- Engineering Properties
- Morphology
- Strength



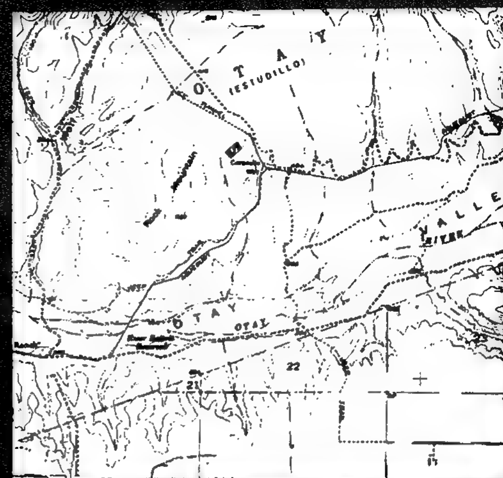
GROUNDWATER

- Location of water table
- Affect geophysical equipment



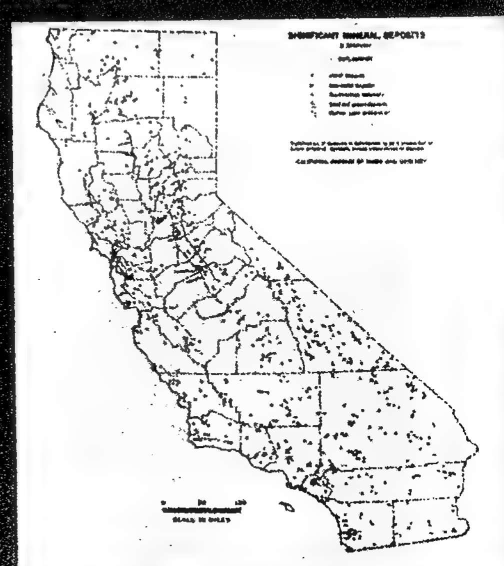
TOPOGRAPHY

- Elevation
- Lakes, rivers, streams
- Landscape
- Forestry



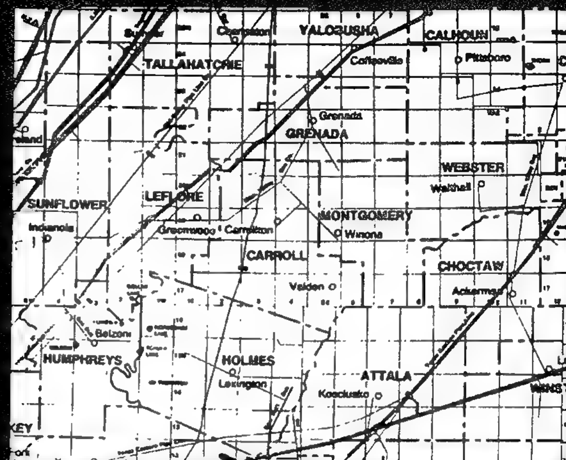
MINING AND MINERAL DEPOSITS

- Location of active mines
- Location of abandoned mines
- Construction materials



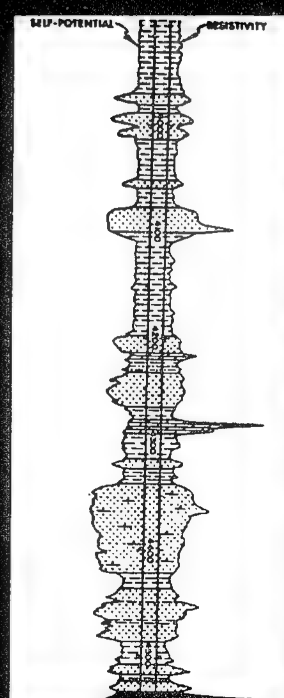
UTILITIES

- Sewer lines, water lines
- Above ground utilities (telephone poles, electric lines)
- Oil and gas pipelines



GEOPHYSICAL

- Various methods
- Lithological information
- Structure (faults, joints, fractures)
- Engineering characteristics

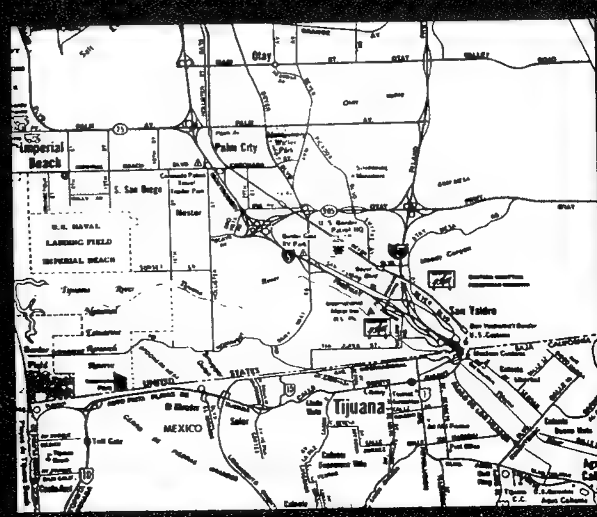


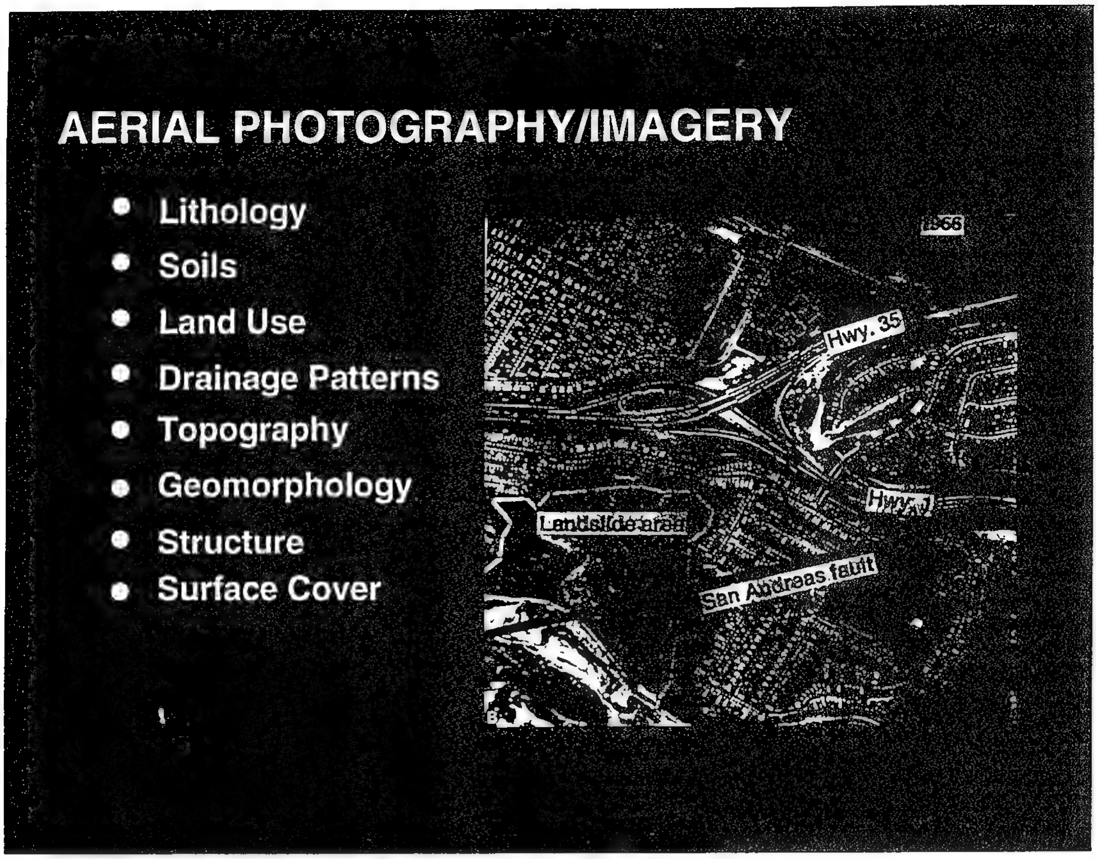
VEGETATION

- Structural characteristics
- Species composition

TRANSPORTATION

- Highways
- Property Access
- Product transportation (methods, distance, etc.)



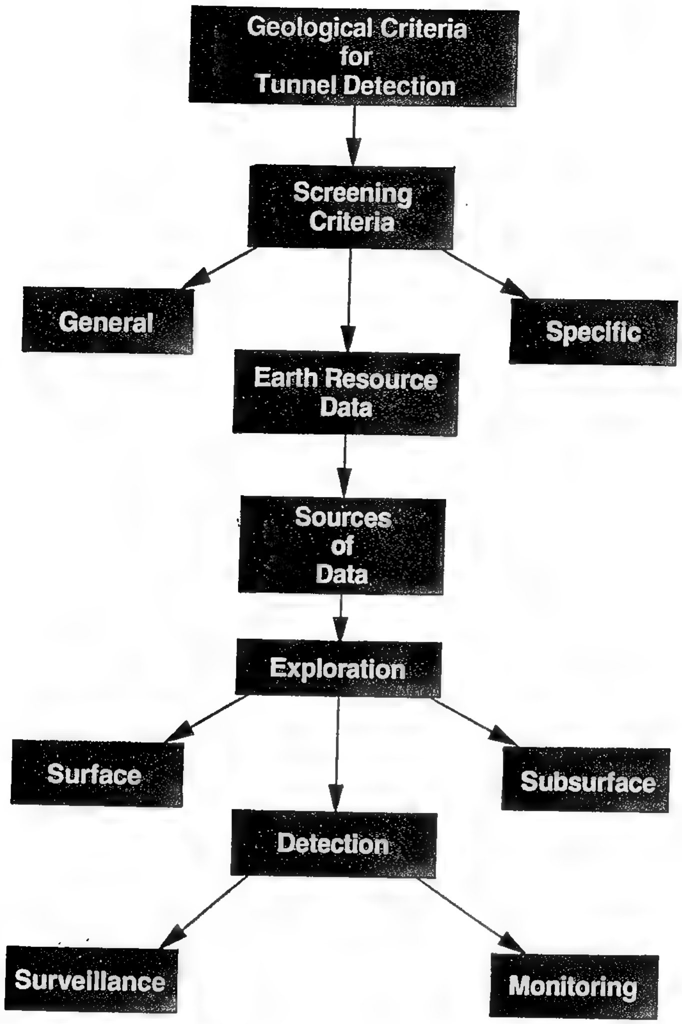

AERIAL PHOTOGRAPHY/IMAGERY
• Lithology
• Soils
• Land Use
• Drainage Patterns
• Topography
• Geomorphology
• Structure
• Surface Cover
1966
Hwy. 35
Hwy. 1
Landslide area
San Andreas fault

Products

- Hardcopy maps
- GIS / digital products
- Reports

Future Project Goals

- Review literature
- Construct a Geological Information Database (GID)
- Incorporate information into a GIS
- Site visits to Douglas, Arizona
  Otay Mesa, California
  El Paso, Texas
- Field investigations


Geological Criteria
for
Tunnel Detection
Screening
Criteria
General
Earth Resource
Data
Specific
Sources
of
Data
Exploration
Surface
Subsurface
Detection
Surveillance
Monitoring

Computer Applications for Tunnel Detection

Mr. Joseph B. Dunbar
Waterways Experiment Station

Abstract

Computer applications in tunnel detection consist of Geographic Information Systems (GIS) for site selection and information management of potential tunnel sites. Computer applications include computer modeling of suspected tunnel sites. A GIS is a computerized database system for capture, storage, retrieval, analysis and display of locationally defined data. Primary advantages of a GIS are its ability to perform rapid querying of multiple data sets, convert different data types to a common format and structure, procedures that incorporate change detection capabilities, and to integrate engineering properties of earth materials into spatial data sets. GIS is a useful tool for data conversion and provides for exchange capabilities with other potential users and agencies. The application of GIS for tunnel detection and information management will provide a method to model geologic, engineering and geophysical data, and display this data visually. The application of GIS and modeling technology to tunnel detection will improve the efficiency of data interpretation and management.

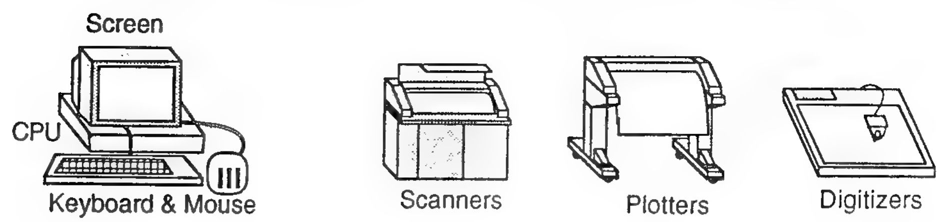
Discussion

LEA: Are you able to change the scale of maps and other information scanned into the database?

SCIENTIST: Map scales can be enlarged or reduced digitally by the GIS. Aerial photography and other scanned imagery can be incorporated and would require rectification to allow exact scale changes. Scanned information is useful in providing a case history and archival database but not practical for manipulating data. Construction of a GIS will follow geologic screening criteria for a specific site.

Hardware and software

■ **Hardware:** workstation or terminal and peripherals



■ **Software:** operating system, GIS software, word processor, data base

Geotechnical Laboratory Computer Applications Lab

- Hardware
  - Silicon Graphics workstations
  - Intergraph workstations
  - Personal computers
  - Digitizing tablets
  - HP printers and electrostatic plotter
  - Scanners
- GIS Software
  - ARCINFO
  - ERDAS
  - Intergraph
  - GRASS
- Geotechnical Modeling Software
  - Dynamic Graphics

Advantages of GIS

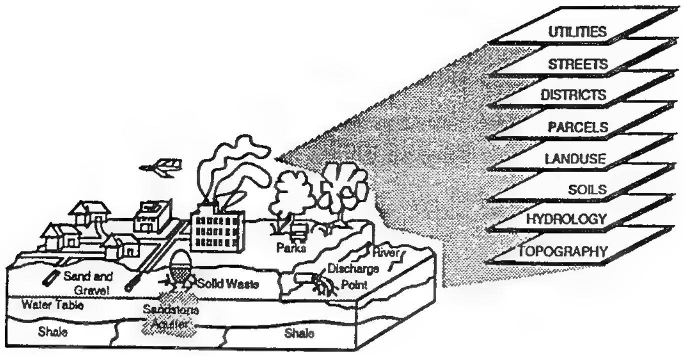
Tool Box of Software Procedures to Organize, Manage, and Make Decisions About Spatial Data

- Flexible to changing inputs
- Open architecture
- Multidisciplinary use
- Common data format and scale
- Long term monitoring
- Improves speed of decision making

Disadvantages of GIS

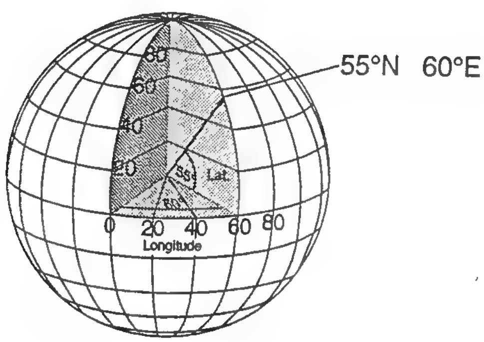
- Hardware requirements
- Personnel training and commitment
- Large startup effort

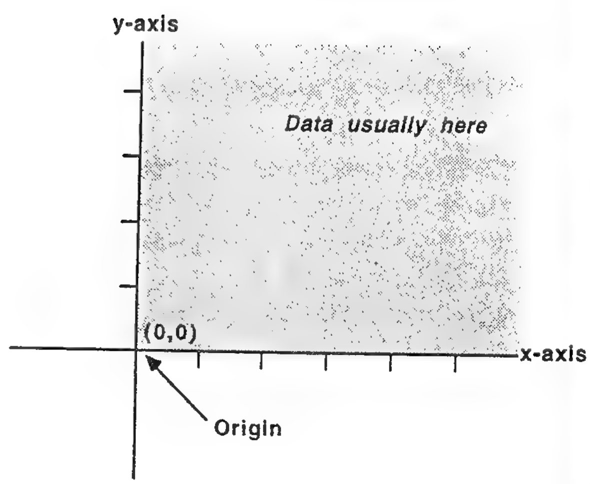
GIS support for decision making



- Real-world problem and supporting database
- Database query and analysis

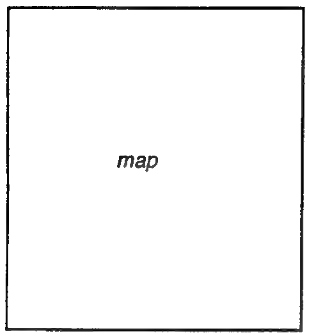
Coordinate systems



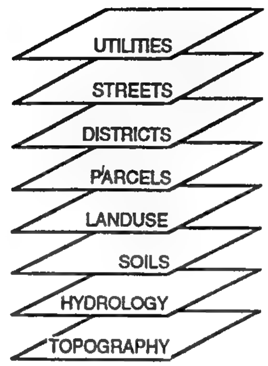


- Spherical coordinate system
- Cartesian coordinate system
  - State Plane
  - Universal Transverse Mercator (UTM)

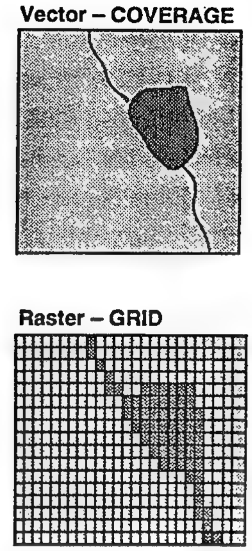
Representing geographic data



■ **Locational data**

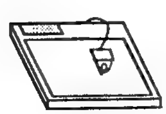


■ **Thematic data**

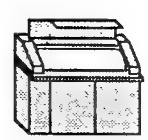


■ **Storage formats**

Converting map and attribute data



Digitizers

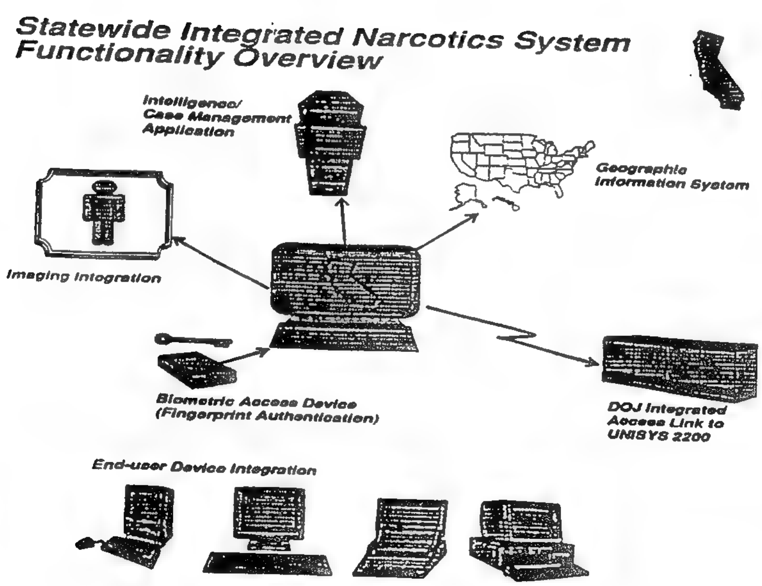


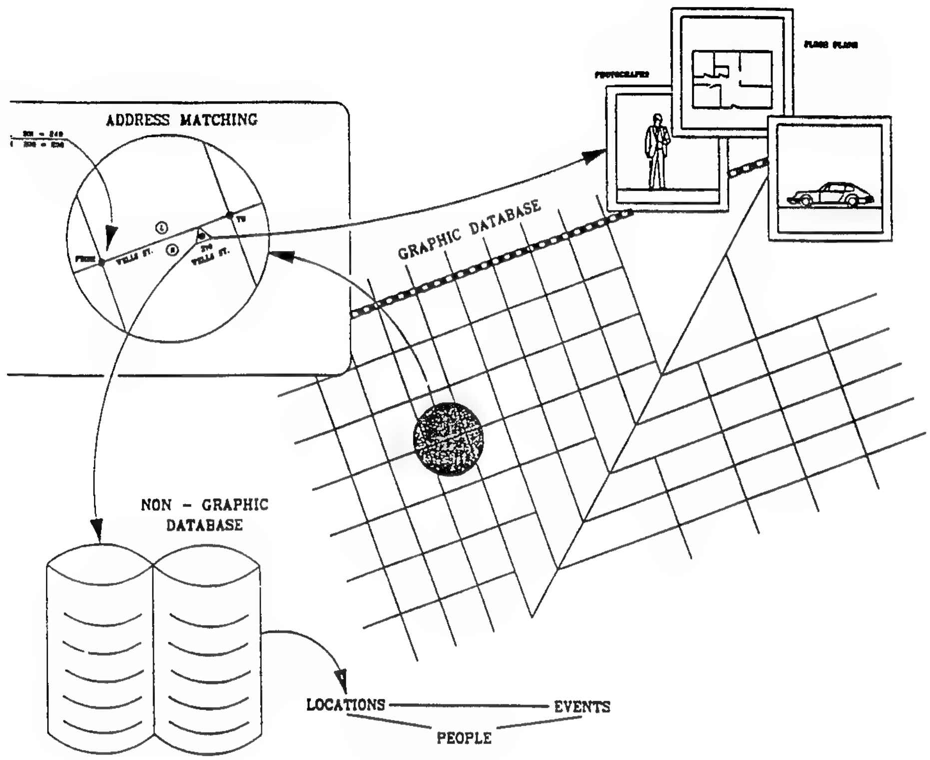
Scanners

Keyboard

Sources of Digital Data

Format	Description
DXF	Exchange format for AutoCAD files and some scanning products
IGDS	Intergraph design file
SIF	Intergraph® interchange file
MOSS	A format for GIS data from some federal agencies
DLG	Digital Line Graph - Roads, Hydrology, etc. - Available from USGS - 1:24,000 1:100,000 1:2,000,000
GIRAS	Geographic Information Retrieval and Analysis System - An older USGS format - Land use, land cover maps at 1:250,000
DIME	Street maps from 1980 census - Street address data and census polygon data
TIGER	Street maps from 1990 census - Street address data and census polygon data




ADDRESS MATCHING
GRAPHIC DATABASE
NON - GRAPHIC
DATABASE
LOCATIONS
EVENTS
PEOPLE

Application of GIS Technology to Tunnel Detection

Site Selection

- Converts data to common format
- Image processing capabilities
- Temporal Data
- Engineering properties of earth materials

Subsurface Exploration and Detection

- Refines testing methods and strategies
  - Geophysical testing
  - Engineering borings
- Supports numerical modeling of selected sites

Application of Computer Modeling to Tunnel Detection

Models Geologic, Engineering, and Geophysical Data

- Numerically models physical site conditions
- Extrapolates and maximizes existing data
- Allows 3-dimensional visualization
- Visually defines areas requiring additional data
- Combines data sets using mathematical models

Application of GIS Technology to Tunnel Detection

Improves Detection Capabilities

- Allows rapid querying and analysis
- Supports data exchange between agencies
- Provides map and digital products
- Unlimited applications

Data Coverages

Physical	Cultural	
Geology	Land use	Highways
Soils	- Agricultural	- Interstate
Elevation	- Residential	- Primary
- Surface	- Industrial	- Secondary
- Groundwater	- Mines	- Unimproved
- Bedrock	Utilities	Property / site history
Structure	- Electric	- Age
Vegetation	- Gas	- Ownership
Drainage	- Sewer and water	
Caves		
Geomorphology		

Sources of Engineering Geologic Data

- Publications, reports, and newspapers
- Maps and surveys
- Photography and imagery
- Field surveys
- Personal contacts

Photography and Imagery

- Land use
- Border distance and building spacing
- Geology
- Geomorphology
- Engineering Characteristics

Tunnel Feasibility of Earth Material

Impractical or Practical

- Competent: Requires no added support
- Incompetent: Requires added support

Computer Applications For Tunnel Detection

Geographic Information Systems

Computer modeling of suspected tunnel sites

Objectives

- Site Selection
- Geophysical Detection
- Information Management
- Other

Geographic Information System (GIS)

- Computerized database system for capture, storage, retrieval, analysis, and display of locationally defined data

Engineering Classification of Earth Materials

Soil

- US Dept. of Agriculture (1960, 1975)
- Unified Soil Classification System, USCS (1953)

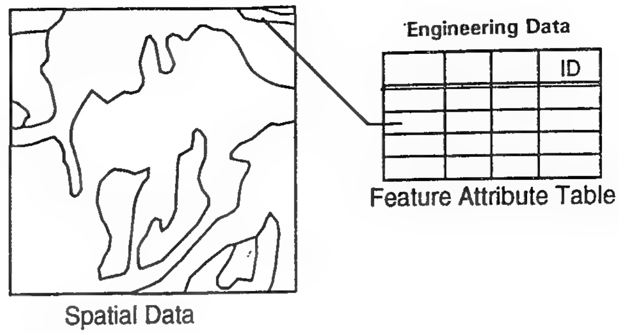
Rock

- Terzaghi (1946)
- Laufer (1958)
- Coates (1964)
- Deer (1964)
- Bieniawski (1973, 1990)

Common Geotechnical Properties of Earth Materials

- Material type (soil, rock)
- Hardness (hard, medium, soft, decomposed)
- Discontinuities (orientation, spacing, condition)
  - Faults / folds (massive, slightly, moderate, or intensely)
  - Bedding planes
  - Jointing
- Weathering (none, slightly, moderately, highly, completely)
- Ground water conditions (gpm; dry, wet, dripping, flowing)
- Geophysical properties (velocity, electrical)
- Engineering properties (shrink-swell, uniaxial compressive strength, RQD)

Associating attribute data with spatial data



Stages of Development for GIS Application to Tunnel Detection

- Data input
  - Obtain existing physical and cultural data
  - Interpret data from photography and imagery
  - Field reconnaissance
- GIS development
  - Digitize, scan, or purchase map coverages
  - Create database of attribute related data
  - Link and relate attribute data to map coverages
- Site selection
  - Develop search criteria
  - Perform GIS queries
  - Identify potential areas or sites
- Field testing and definition
  - Geophysical surveys
  - Engineering borings
  - Numerical modeling of selected sites
- Report results of geologic screening
  - Maps, digital products, reports

Example of Search Query

- Rock or soil type
- Ground water conditions
- Discontinuities
- Land use
- Distance from border
- Utilities present

General Recommendations

- Develop site GIS of known tunnels
  - Otay Mesa, San Siego, CA
  - Douglas, AZ
- Develop regional GIS

Recommendations For Regional GIS

Continue Development Of Existing SW Border GIS

- JTF6 and US Army District, Ft. Worth
- Provides environmental support to military activities
- Current status: incomplete

SW Border GIS

Available Data

- TM data
- Soils
- Vegetation
- Geology
- Cultural features
- Topographic

Geographic Information System Uses For Tunnel Detection

Goals

- To provide an understanding of how Geographic Information Systems (GIS) can be utilized in tunnel detection
- To stimulate the further development of applicable ideas

GEOGRAPHIC INFORMATION SYSTEM SUPPORT TO JOINT TASK FORCE SIX

The Fort Worth District of the U.S. Army Corps of Engineers has been working for approximately two and one-half years on the creation of a Geographic Information System (GIS) of the U.S./Mexico border region. The intent of the GIS effort is to provide support, in the form of maps and statistical reports, to persons involved in the counter-drug mission of JTF-6. It should be noted that this work effort was never intended as an academic study, but rather to provide a deliverable product to support the overall JTF-6 engineering mission. It is the intent of this effort that maps produced from this GIS be used as aids in the decision making process, and not as "gospel" representations of the potential impact areas for a given action. It is also important to note that this is a dynamic product, meaning data layers included in the system are in a constant state of refinement and development.

This GIS effort is being performed in cooperation and conjunction with several other academic, state and Federal agencies. Communication between these various organizations was initiated, and will continue, in an effort to avoid duplication of digital databases and to create a cooperative working relationship between the various parties.

The engineering actions performed by JTF-6 personnel are quite diverse, ranging from reconnaissance operations to the construction and maintenance of roads and radio towers. Many of these actions have some degree of impact on the environment. The National Environmental Policy Act (NEPA) of 1969 requires that an attempt be made to evaluate the consequences of any proposed action by any Federal agency on the environment. Other Federal acts which must be considered before initiating JTF-6 actions include the National Historic Preservation Act of 1974 and the Endangered Species Act, as amended in 1973.

In an attempt to address and avoid any potential environment impacts of the various JTF-6 engineering actions in a timely and efficient manner, the Environmental Section of the Fort Worth District, U.S. Army Corps of Engineers, in conjunction with the JTF-6 command has established a region-wide GIS. The study area for this GIS effort includes the entire U.S./Mexico southwestern land border and 40 miles (64.36 km) in on the U.S. side. This study area has recently been enlarged to include the entire Texas Gulf coast. Portions of California, Arizona, New Mexico, and Texas are included in this study area with each state having its own special requirements, concerns and contacts for environmental, cultural, and social concerns. The GIS is intended to facilitate the identification of these various concerns throughout the study area.

WHAT IS A GIS?

A generic definition of a GIS is a computer system which allows the input, storage, display, manipulation, maintenance, and analysis of spatially referenced data. Spatially referenced data refers to maps, where the position of

various features on the map are situated in a scaled relationship to one another. The most important aspect of a GIS is its ability to analyze data in ways that are not readily achievable with hardcopy maps. A good example of this capability is the ability to overlay various thematic map layers to produce an output product that represents a logical combination of the two layers (ex: creation of a new map showing soils overlaid with roads and contours). Another common analysis technique is the ability to combine maps of various scales easily in the computer environment. Requestors of these data are encouraged to use their imaginations in determining which map layers would be helpful to them. The analytical capabilities of the GIS make the derivation of new map layers from existing map layers quite easy. We rely on user's input to tell us what type of products are needed so we can determine the level of effort demanded by the request.

One major benefit of a GIS is the reduction in storage requirements from hardcopy maps. The GIS will allow the user to store these maps as digital data files that can be printed in hardcopy form on demand or simply viewed on the computer screen when a hardcopy is not required. Updating and maintenance of these map layers becomes a relatively easy task in the GIS environment. Additions or changes to the map are made to the digital file and saved on the computer system. The actual computer system for this work effort resides at the Corps of Engineers office at the Fort Worth District. Formal requests for the data are channelled through this office.

DIGITAL MAPPING

Recent improvements in the processing and storage capabilities of computer systems have allowed for the advancement of digital mapping techniques. Digital mapping simply refers to spatial data, such as maps, being stored in the computer rather than in hard copy. This allows the computer to perform rapid analyses of the data in a way which has before been almost impossible, and also makes updating and physical storage of these maps much easier. These analytical capabilities allow the user to create "what-if" scenarios and to perform spatial modeling with the various map layers. A list of potential questions or products your staff may request of these data is provided at the end of this report. This list is only an example to show you some potential uses of these data.

Numerous digital data layers were created or compiled for this effort. Input of the various maps into the computer system is, in many cases, a long and tedious process involving the manual tracing of the lines of a paper map using a digitizer to convert the traces into digital map files. It is very important for the end users of these data to be aware of the original source, scale, resolution, and accuracy of these various data layers in order that the limitations of the map layers are realized when making decisions which may affect the environment.

Digital data are stored in three graphic representations: raster, vector, and site. These three data representations can be summarized as follows:

Raster - a set of cells, or grids, located by coordinates, where each cell is independently addressed with the value of an attribute.
Vector - composed of points and lines; linear features such as roads, streams, and contours.
Site - or points, are similar to cells, except they do not cover areas.

Data stored as grids or as a matrix of squares in the computer are referred to as a raster system. Each grid cell, or pixel, is referenced by a row and column number and it contains a number representing the type or value of the attribute being mapped. In raster structures a point is represented by a single grid cell which has a resolution that reflects a horizontal aerial extent on the ground. The Landsat satellite imagery used in this study, and indeed all satellite imagery, is stored as raster files, with each pixel on the screen representing approximately 25 m on the ground.

Vector data representation is an attempt to display the data as accurately as possible. Vectors consist of lines and nodes (points where lines converge). Attribute data, such as a topographic contour value or a building number, can be assigned directly to the vector itself. In many instances, vector data, such as roads, streams, or contours, are displayed as visual overlays on a background raster map.

Each site, or point, is represented by a single x y coordinate pair. Like vector data, attribute data describing that point can be attached directly to a point. Examples of this would be individual spot elevations or archaeological site information.

DIGITAL DATA LAYERS

Following is a partial list of the digital data layers produced or compiled for this project. More detailed descriptions of each of these map layers follows in this section.

RASTER MAPS	VECTOR MAPS	SITE MAPS
Soils	Roads	Archeological Sites
Geology	Streams	Endangered Species Sites
Surface Topography	Railroads	
Aspect	Powerlines	
Slope	Political Boundaries	
Land Cover		
Viewshed Coverage		
3-D Coverage		
Endangered Species Habitat Ranges		
Landsat TM Satellite Images (31 total)		

A fundamental base layer for the GIS is the 31 Landsat Thematic Mapper (TM) satellite images obtained for this mapping effort. These commercially available data are imaged from a satellite platform in a 438-mile polar orbit above the earth. The spatial resolution of these data is 25 m. This means

that each pixel, or grid cell, on the image represents 25 m on the ground. Seven separate spectral bands of data are provided for each scene. The bands represent not only those light frequencies visible to the human eye (blue, green, and red) but also wavelengths in the near, middle, and far infrared (including thermal) portion of the spectrum. Each pixel contains a reflectance value (digital number) for all of the seven spectral bands. A wealth of information, ranging from geologic delineations to land cover assessments, can be derived from these data by using specialized image processing techniques.

Examples of potential queries for the GIS:

Provide a map of roads, streams, and contours (50 ft) overlaid on a map of geology for our project area.

Provide a map of the project area which shows a 50-m buffer away from the proposed project road work, showing existing roads, streams, and 50-ft contours.

Provide a map of our project area that shows where our project will cross a certain soil type.

Provide a map showing where our project will cross areas greater than 20 percent slope on a particular soil type.

Provide a map of all known threatened or endangered species sites within our project area.

Provide a statistical breakdown by acres, hectares, and square miles of the amount of the various land cover type within 100 m of the proposed road work.

Provide a map showing everything visible for 5,000 m in every direction from a given point.

Provide a three-dimensional perspective view of the land-cover facing north from a specified point.

DATA REQUEST PROCEDURES

In order to process requests for data in an efficient manner, it is necessary to establish a standardized request procedure. When making a request for map products, we ask that you keep in mind that this is just one of many large GIS projects handled by our very limited GIS staff. We will put a top priority on any data request; however, it will not always be possible to process each request immediately. The amount of digital data required for this project is huge, and even with our fast computers, a considerable amount of time is required to load and process the data for any given area.

Due to the time required to load, analyze, process, and print the digital data, we ask that the requestor make an informed request for only those data layers and reports which are determined to be useful and beneficial to the successful completion of the projected mission. In others words, we strongly discourage blanket requests for all data on a particular area.

The following is offered as guideline checklist for the request of data stored in the GIS:

1. We ask that your unit establish a single point of contact (POC) to deal with our office on data requests. This should reduce confusion and eliminate the possibility that we may get duplicate requests for information on the same project. Contact either Scott Walker (817) 334-3246 or Tom Nelson (817) 334-2095, U.S. Army Corps of Engineers (CESWF-PL-RE), P.O. Box 17300, Fort Worth, TX 76102-0300

2. Have your POC review this document thoroughly to become familiar with the types, sources, and resolutions of the various data layers. Much of the information presented here is of a technical nature, and it will be of value in deciding the appropriate uses for each individual map layer.

3. Contact our office with specific requests for data. Again, we strongly discourage blanket requests for all data within a certain area. Please take the time to review the data layers we can provide and determine which of these data would best assist your unit in the successful completion of your JTF-6 mission. Be aware that certain data layers may not be available yet for all areas. We are making our best effort to fill any gaps in the data, but this is a huge project and complete coverage will take time. If we do not have a particular data layer in your area of interest for a current project, please don't hesitate to ask for the same data again if you happen to have another action in the same area at some later date.

4. Give us as much advanced warning of an impending action as possible. We request that you give us a minimum of two weeks for turnaround on data product requests. Please understand that on larger study areas, the time required to process these digital data increases and so will turnaround time. Please be patient with us. We will attempt to process your order as quickly as possible.

5. Certain data we may provide to you is sensitive in nature. The very location of many of these actions is not always public knowledge, and maps and information sent to your unit by our office should be treated accordingly. We ask that you contact JTF-6 before releasing any of these data to the public. Certain data layers, such as archaeological site data and endangered species locations, are also considered privileged, and should only be distributed on a need-to-know basis. In the case of archaeological site data, certain agreements had to be made with the proprietors and/or suppliers of the data to assure that the data would remain protected. Please respect the privileged nature of these data.

6. Once you receive your data, be sure to review the level of detail provided by each map layer. Make sure that the data layers are appropriate for the intended purpose. The potential for misuse of these data exists, and it is up to the users of the data to use it in a wise manner.

Geographic Information System Uses for Tunnel Detection

Mr. Gary W. Hennington
Information Management Systems, Inc.

Abstract

A demonstration of GIS uses as applied to tunnel detection was shown both by traditional means and with a computer demonstration. The main thrust of the demonstration was to generate feedback which could be used in an actual site-specific GIS.

This type of GIS has two goals: (1) to help in the detection of clandestine operations, and (2) to aid in information management of a specific study area. For tunnel detection, a process of elimination is used. Information layers (such as geology, roads, etc.) of different types are used to narrow the search area of possible site locations.

The geology, for example, shows areas supporting tunneling activity. The speed of the computer-based GIS can be seen by applying a buffer zone around possible transport roads to be used as a search area for possible contraband operation facilities. Groundwater plays an important role in possible tunnel locations. This type of information can be incorporated easily into the GIS both two- and three-dimensionally. Three dimensional modelling and volumetrics can play an important role in helping scientists visualize subsurface conditions.

Many types of graphical features can be stored in a GIS. These features can be attributed with both tabular and other graphical data. An example would be the storage of both property ownership records and an actual picture of the property. GIS has proven valuable in many types of research needs; clandestine operation detection and monitoring should be no exception.

Discussion

LEA: A GIS is precisely the type of information that could be invaluable to us to present complex information to a judge.

SCIENTIST: Geologic and geophysical records would be available to back up this information in the GIS.

SCIENTIST: A three-dimensional line of geophysics can be placed over an area to show the geophysical response to the complex model.

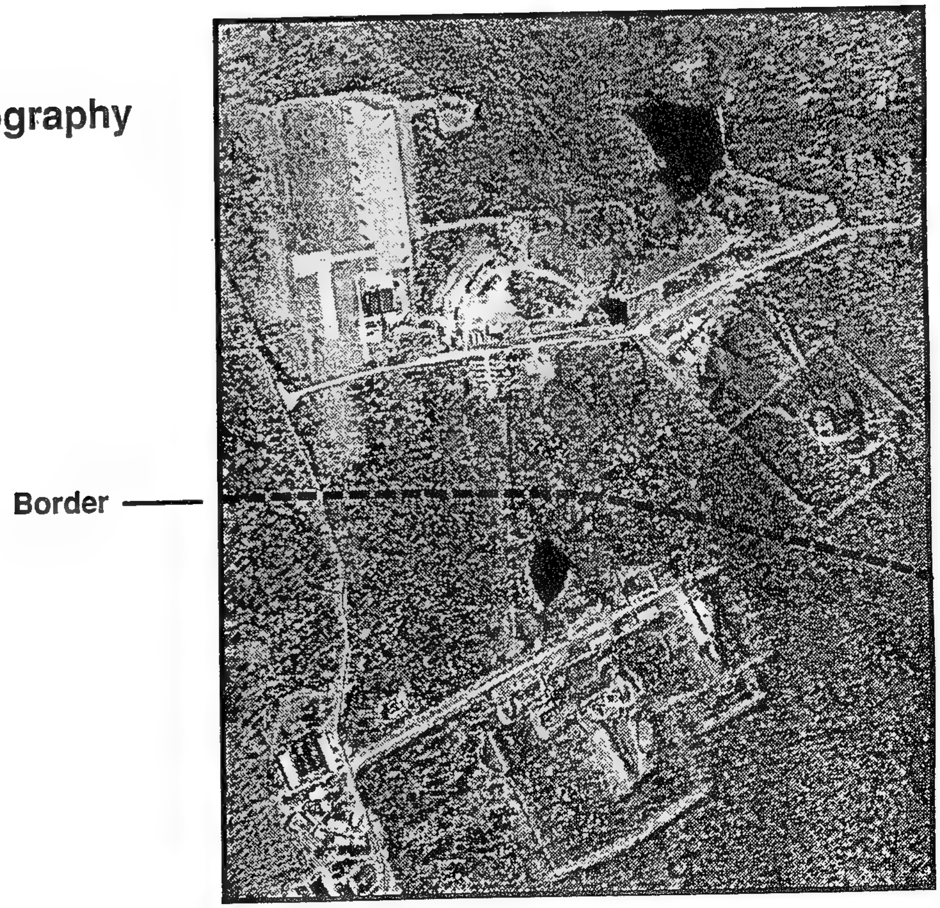
SCIENTIST: Anything can be placed in the database including digital scans of a photograph. Land ownership for the entire area could be stored in the database if required.

LEA: Will this information be on a CD ROM?

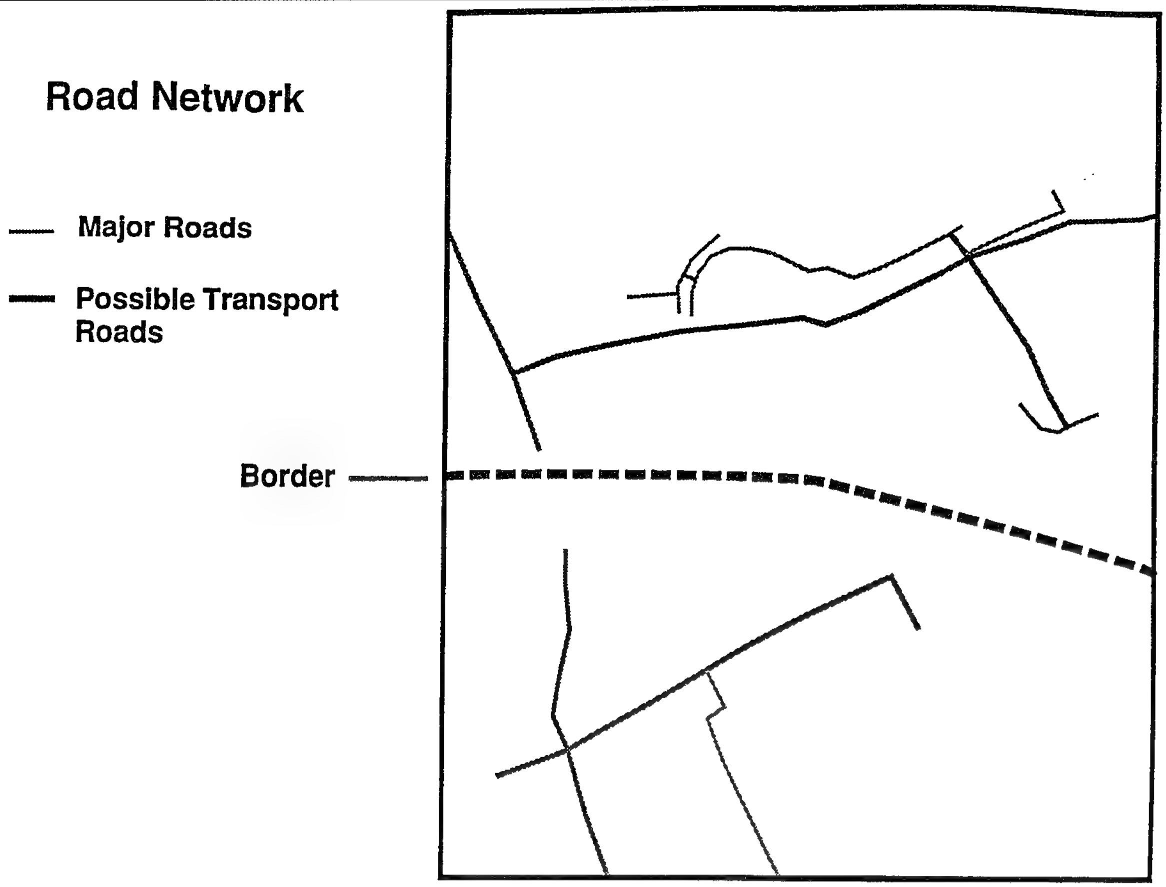
SCIENTIST: Most of the time databases in a GIS are constantly being updated with new information. Data could be transferred to a CD ROM if needed.

Satellite and Aerial Photography Interpretation

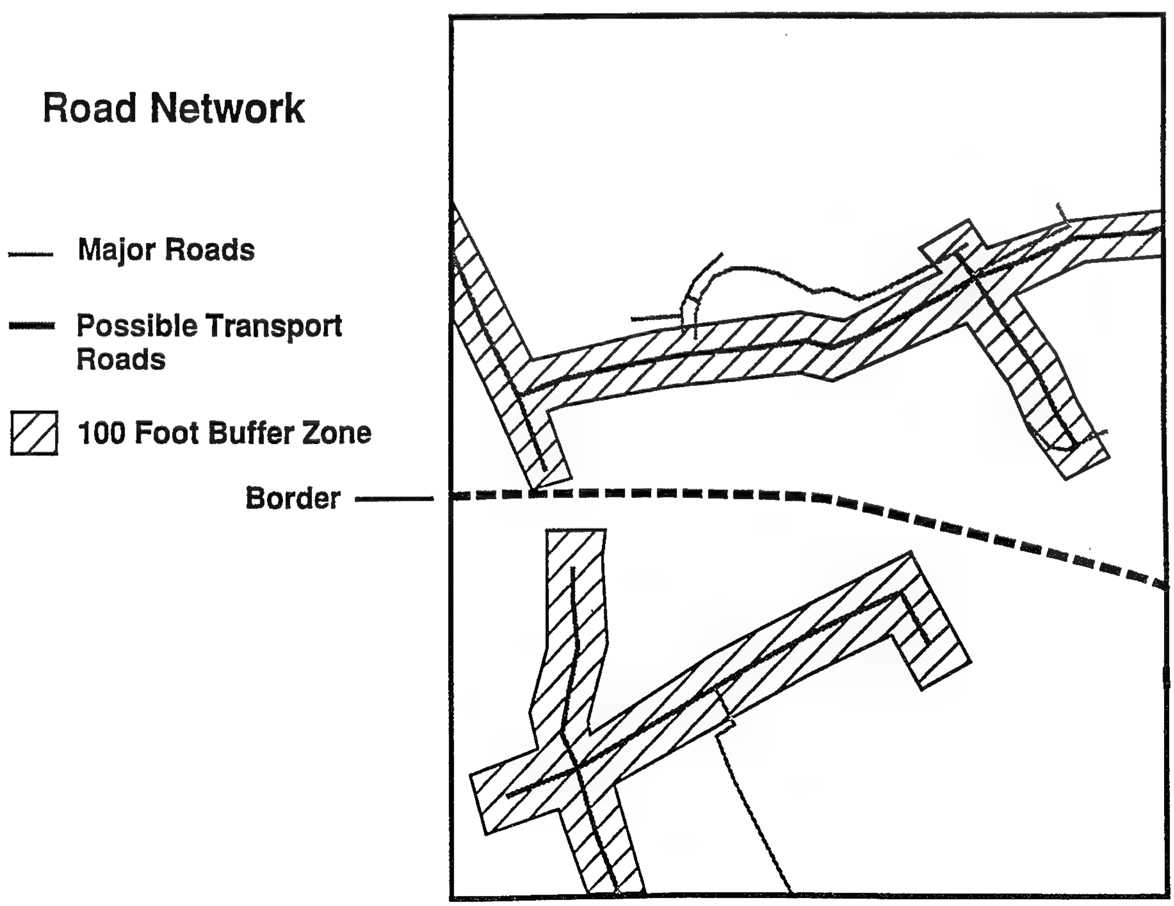
Aerial Photography



Road Network



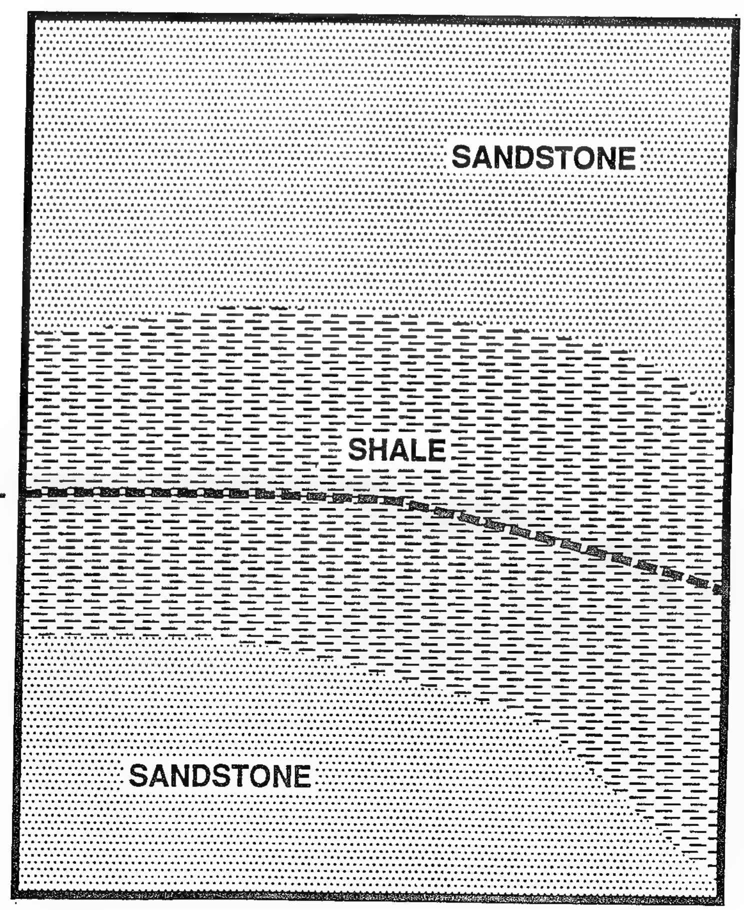
Road Network



Known Locational Quantities

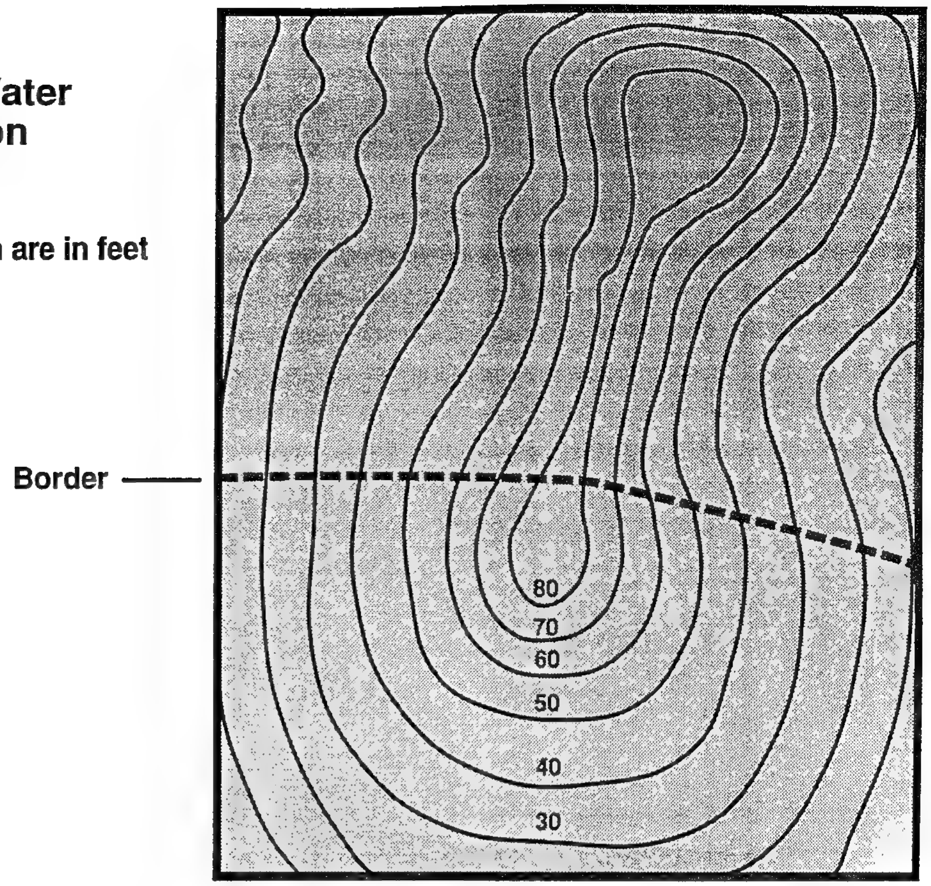
Geology

Border



Ground Water Elevation

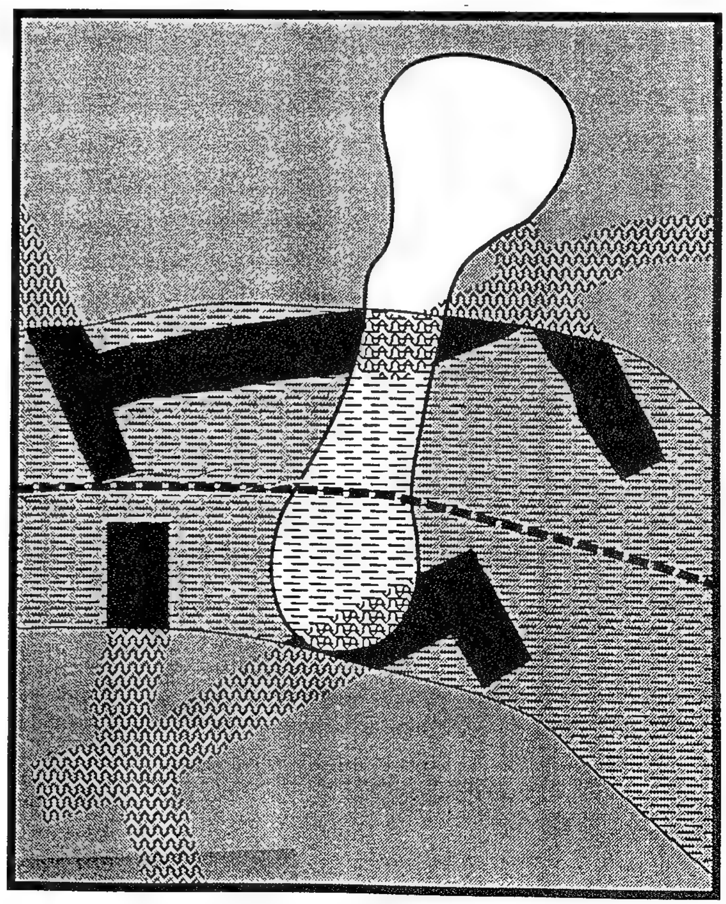
Elevations shown are in feet



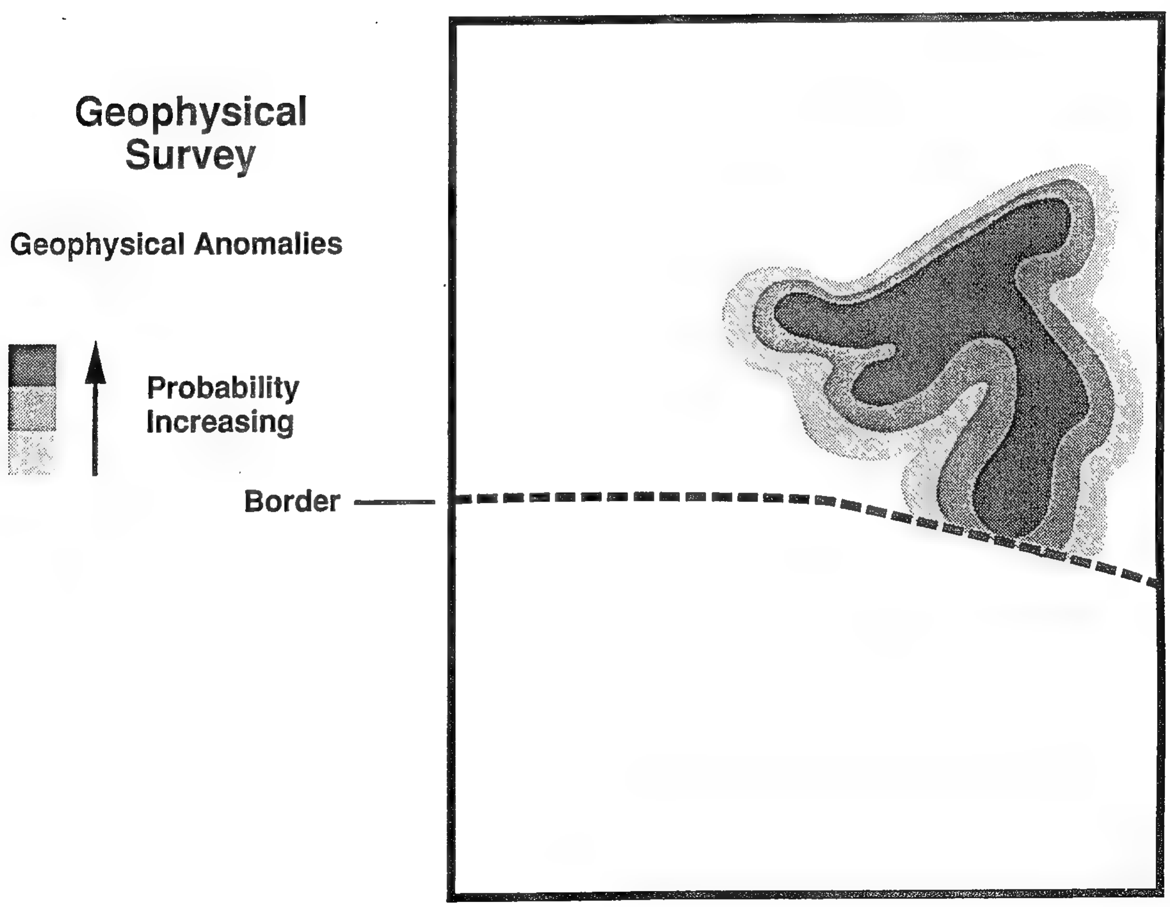
Elimination Map

Areas of High Probability

- Ground Water Probability
- Geologic Probability
- Road Buffer Zone
- Intersected Probability
- Border



Further Refinement Through On–Site Surveys

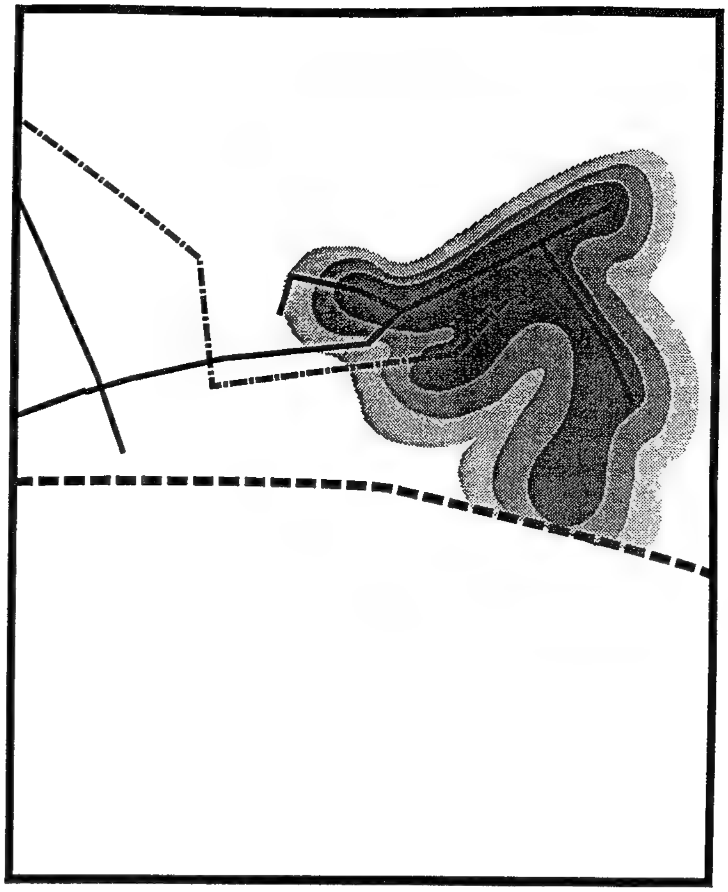


Geophysical Interference

— Power Lines

-·- Underground Utilities

Border ———

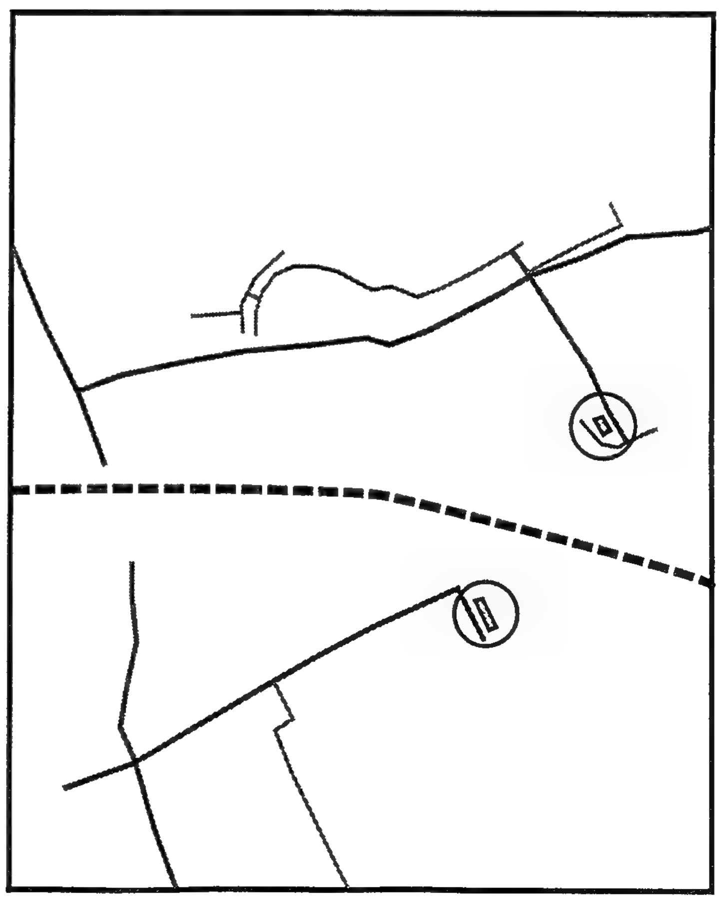


Possible Loading Areas

— Major Roads

— Possible Transport Roads

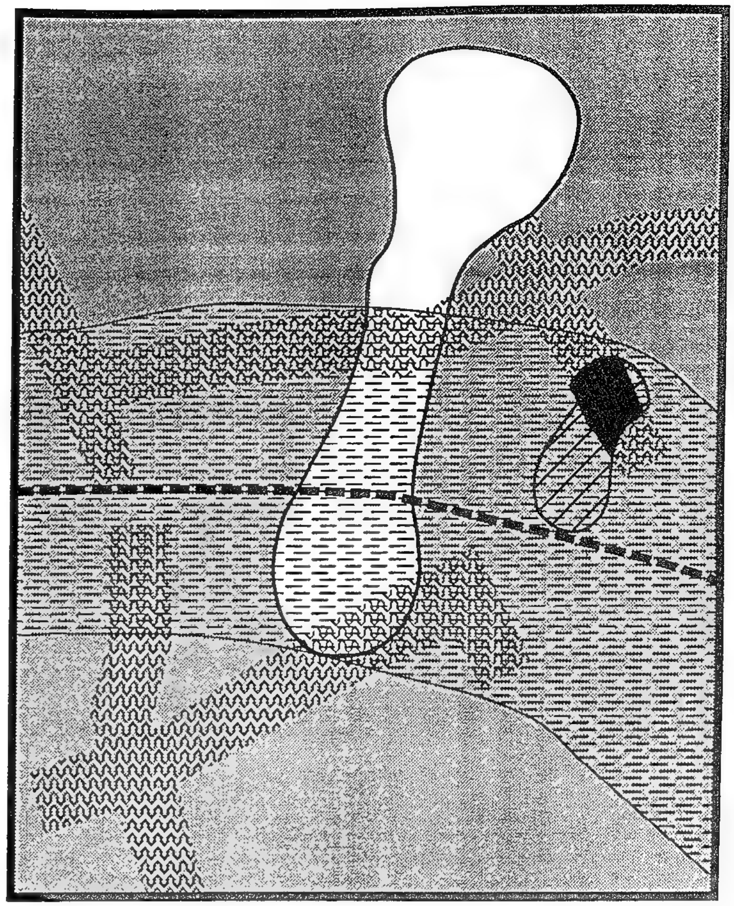
Border ———



Elimination Map

Areas of High Probability

- Ground Water Probability
- Geologic Probability
- Road Buffer Zone
- Geophysical Anomaly
- Intersected Probability
- Border



Conclusions

GIS should be used in future tunnel detection efforts.

Many types of quantitative data sources can be utilized.

PANEL DISCUSSION

Purpose

This panel discussion was devised to give scientists an indication of the questions LEA and DOD may have concerning tunnel detection. Discussions were open and did not follow a topic outline. The summary below has been paraphrased to present pertinent issues.

Panel Members:
Colonel Richard Lunsford, HQ AMC
Rich Gorman, DEA
Jack Trela, FBI
Bob Claborn, U.S. Customs
Larry Caver, U.S. Border Patrol

Summary of Discussion

No agency can singlehandedly prove or disprove the presence of tunnels. Sessions such as these are needed to provide specialized information from each agency to aid in tunnel detection. The priority of the tunnel detection mission is to determine what type of help is needed and where it is needed. Secondly, a test bed should be available to test research and development projects.

Law enforcement keys in on what is out of the ordinary and identifies articulable facts that lead to probable cause for making an arrest. Agents patrolling the border on a regular basis need to be educated to recognize these facts. Education lies in the combination of knowledge of the LEA and scientists.

It is unlikely that a tunnel will be found without good intelligence. The tunnels that have been discovered have had informant or intelligence information identifying specific locations. Before scientific research was conducted on these sites, LEA's had completed preliminary investigations on the property. Law enforcement would hope to have a cooperating defendant or a cooperating witness that can provide evidence to identify a tunnel without technical support. If an area is suspected of tunnel activity, then the LEA has the responsibility to prove or disprove the suspicion. In previous discoveries, tunnel detection operations were conducted in a covert manner and evolved into an overt operation with drilling rigs used to confirm or deny their existence.

Although construction of the discovered tunnels is primitive, other tunnels would probably be similarly constructed. Narrowing the border to site specific areas is more feasible than studying the entire border. There are thousands of miles of border expanse where there is minimal possibility of tunnels across the border. The LEA is looking to the scientist to provide technology needed to pursue an investigation when intelligence is not available or corroboration is required.

There is equipment, such as gravity gradiometers, that is being developed now that will be suitable for tunnel detection. Theoretically, the gradiometer prototype does have merit, but it must be field tested to determine the extent of its usefulness. If, in fact, it worked and since it is a prototype piece of equipment, the commitment has to be made by law enforcement agencies that they will support production of that equipment.

Neither DEA, FBI, Customs, or Border Patrol budgets provide or allow funding for this type of research and development. Funding must come from ONDCP or some other agency. The Counter-Drug Technology Assessment Center is intent on monitoring tunnel detection. The objective is to coordinate at the national level this type research. One of the plans is to develop a radar, one that is already in existence, to test on the Otay Mesa tunnel.

Once equipment has been tested and proven effective on the ground, it can be elevated to an airborne platform. The border could then be flown at regular intervals to discern whether or not activity is taking place. This periodic surveillance would provide a way to track indicators of tunnel construction. The LEA would then be provided this data to corroborate intelligence from informants.

When LEA's apply for search warrants or affidavits, they rely on scientists to be experts in the field to provide backup information that could be included in warrants. The scientist must be responsible for the accuracy of information and understand that the LEA's will use this information in a court process. There are mechanisms involved that would allow the scientist to provide classified information, if necessary.

The fact that a tunnel exists can imply illegal activities that could encompass multiple LEA missions and/or jurisdictions. Hence, all LEA organizations must become involved.

Strategy for Tunnel Detection Using Geophysical Techniques

Mr. Donald E. Yule
Waterways Experiment Station

Abstract

Tunnel detection is an information gathering and processing task which depends on an integrated database composed of geographic, geologic, geophysical, engineering, and target information. Successful tunnel detection and surveillance will involve an interdisciplinary approach between law enforcement and geoscience personnel. Law enforcement agencies will provide direction and guidance to the geoscience technicians who will plan, collect and analyze data to aid tunnel detection and location. The criteria for selecting geophysical search techniques will be scope of operation, operational environment, available resources, target and site responses, and effectiveness ranking. Recommendations for improving tunnel detection capabilities are developing an integrated geoscience database to aid tunnel detection efforts and developing geophysical search techniques to better meet the needs of this application.

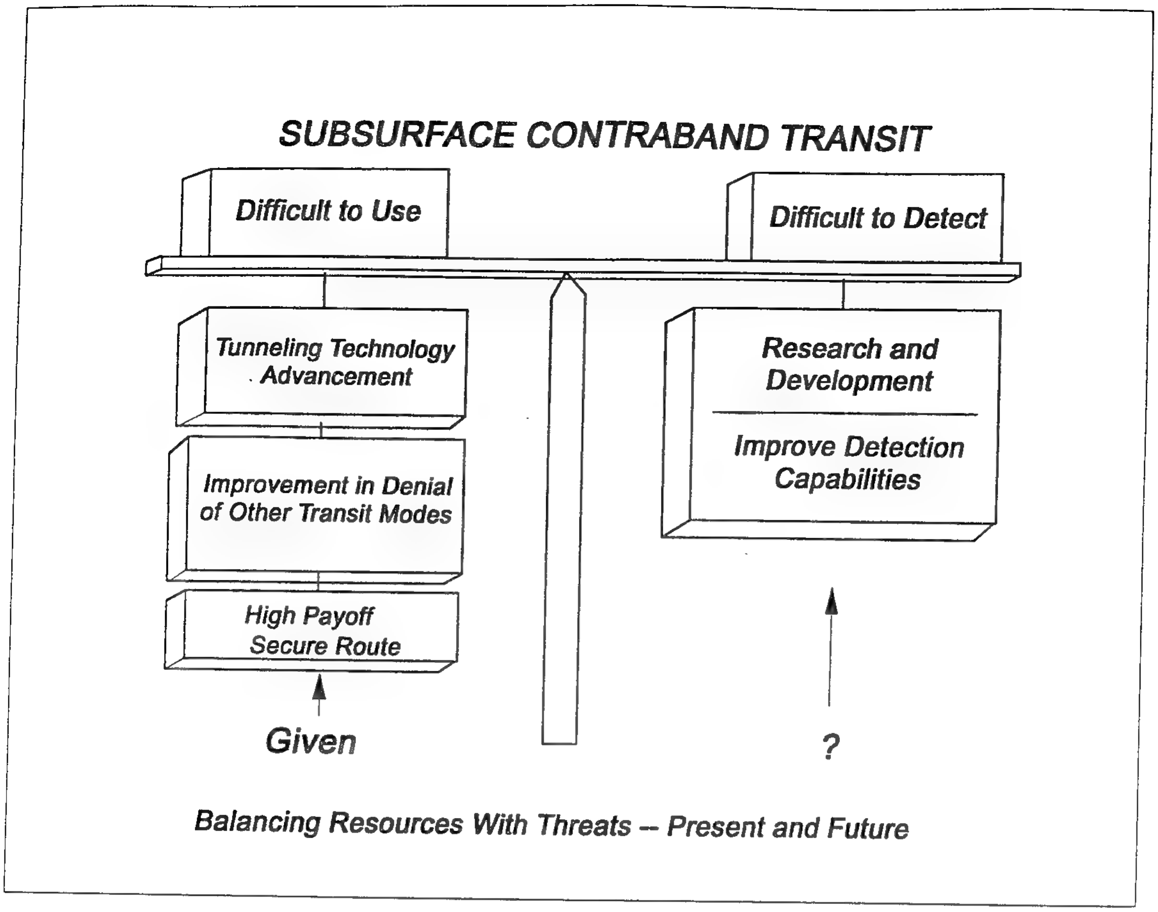
Discussion

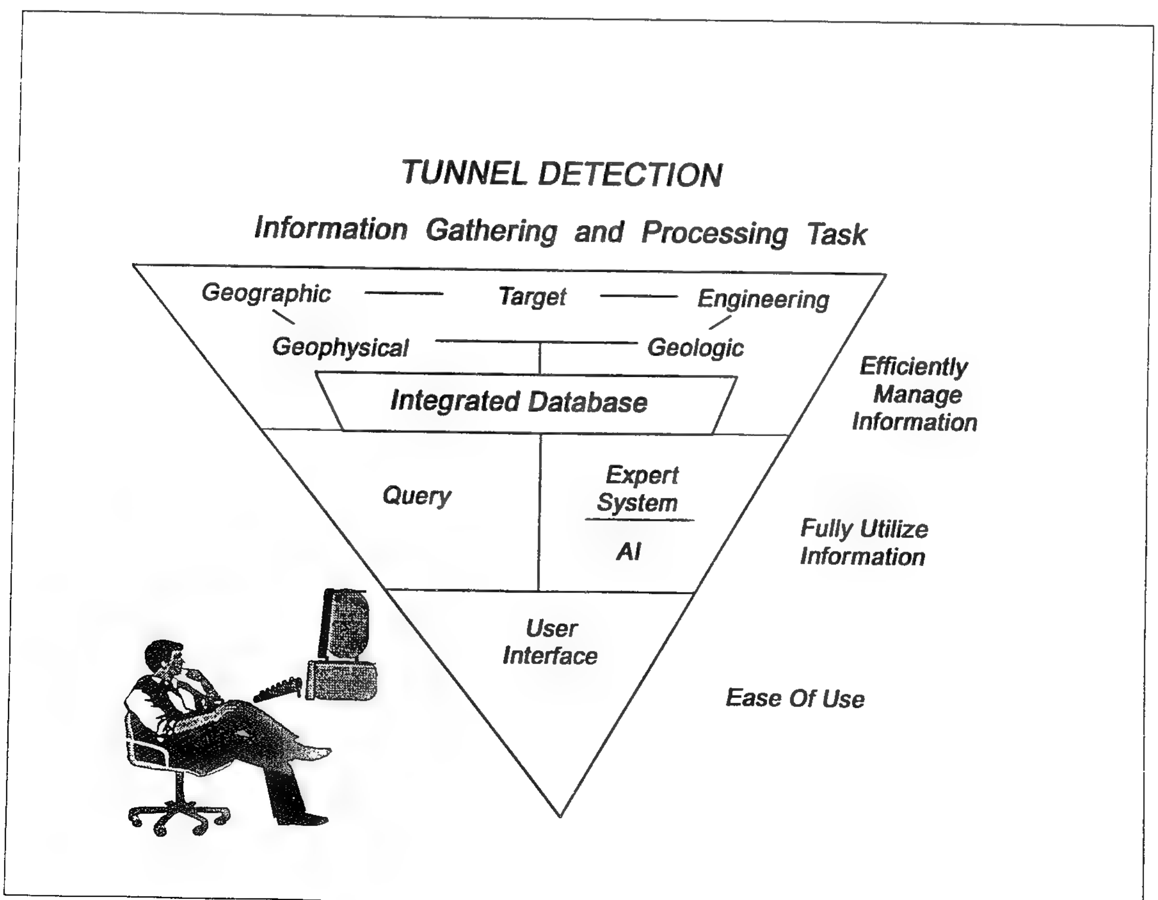
SCIENTIST: You cannot rely on just market forces to deliver a covert system. It could happen, but it would be faster if we (the scientists and LEA) did some work in that direction.

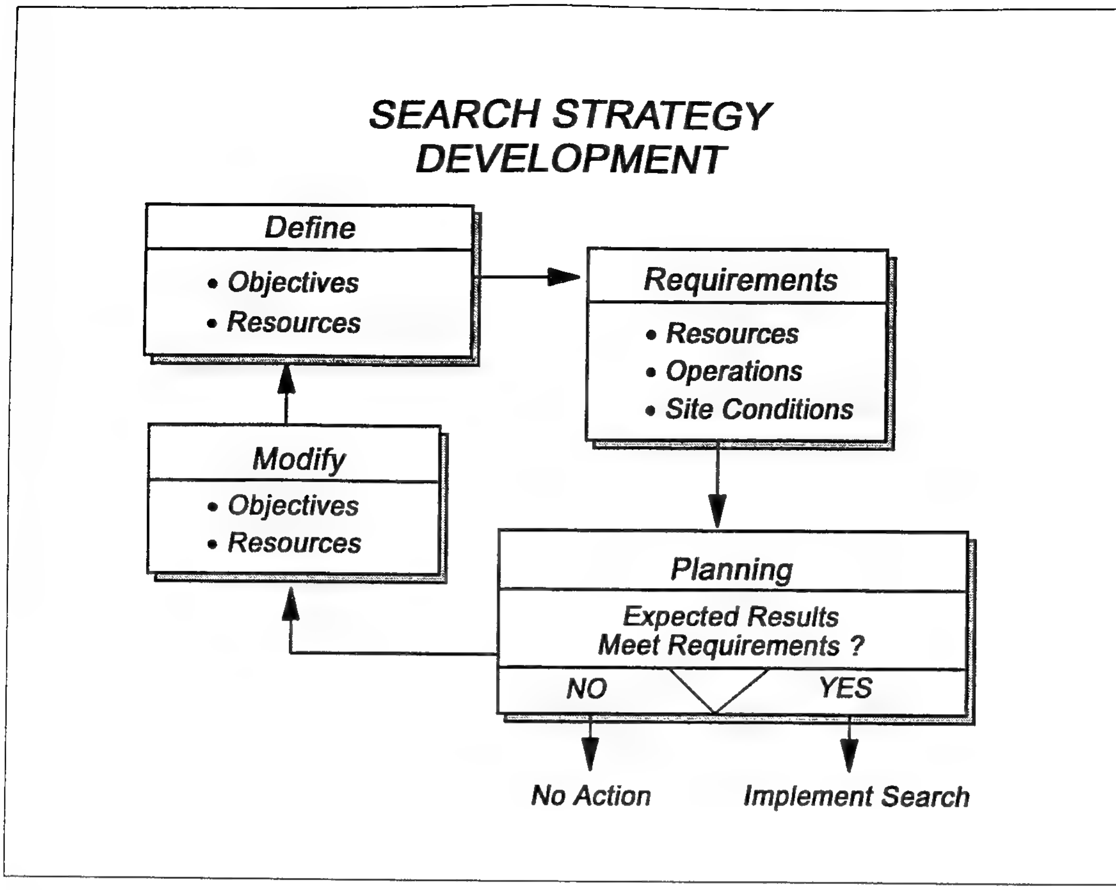
LEA: Who would be the best source of funding for that? The budgets of DEA, Customs, and Border Patrol do not allow for research and development of this type.

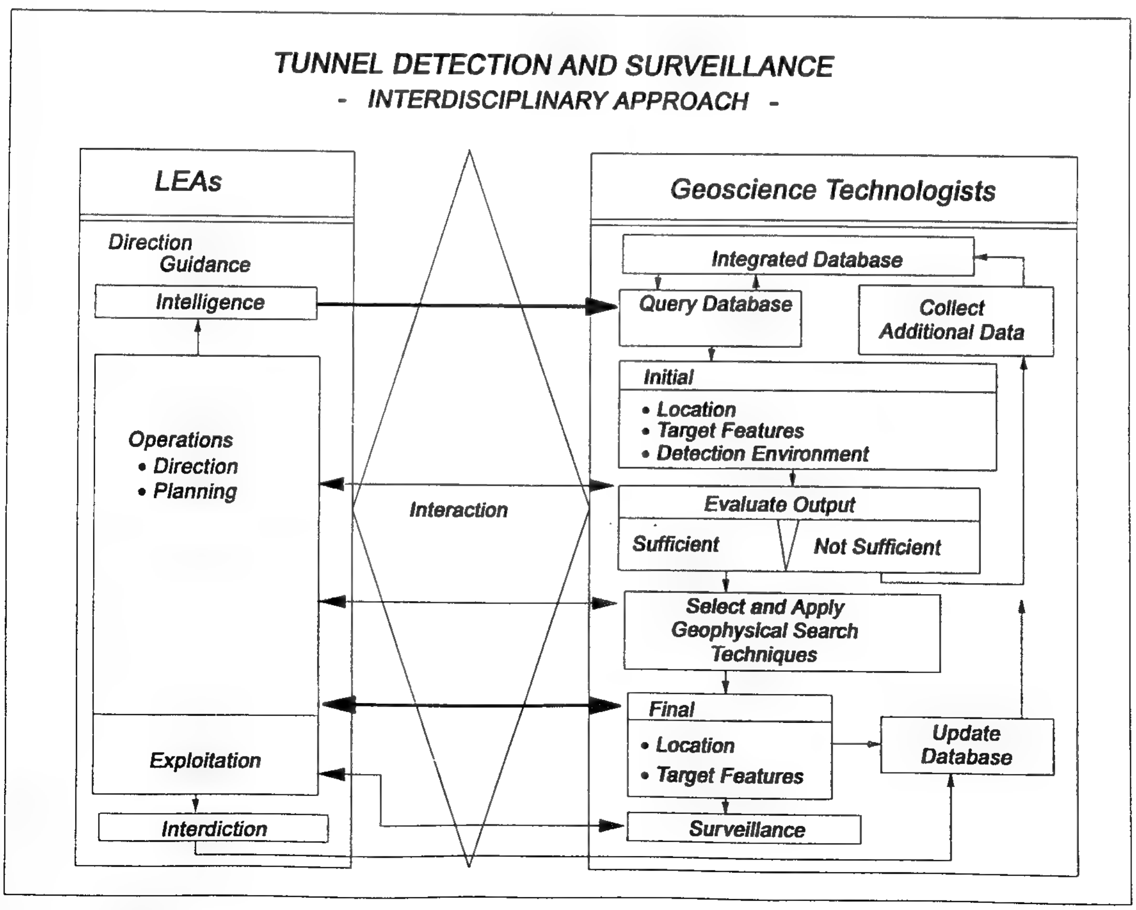
LEA: We are in the process of looking at a variety of options to go with the tunnel detection system (specific funding was not discussed).

LEA: With all the scientists and geologists available, I would like to see a proposal for an environmentally safe way of sealing the tunnels if and when they are detected. We do not want to put 1,100 cu ft of concrete into the tunnel and then have the county tell us it is not environmentally safe.


SUBSURFACE CONTRABAND TRANSIT
Difficult to Use
Difficult to Detect
Tunneling Technology Advancement
Improvement in Denial of Other Transit Modes
High Payoff Secure Route
Research and Development
Improve Detection Capabilities
Given
?
Balancing Resources With Threats -- Present and Future


TUNNEL DETECTION
Information Gathering and Processing Task
Geographic
Target
Engineering
Geophysical
Geologic
Integrated Database
Efficiently Manage Information
Query
Expert System
AI
Fully Utilize Information
User Interface
Ease Of Use


SEARCH STRATEGY DEVELOPMENT
Define
• Objectives
• Resources
Requirements
• Resources
• Operations
• Site Conditions
Modify
• Objectives
• Resources
Planning
Expected Results Meet Requirements ?
NO
YES
No Action
Implement Search


TUNNEL DETECTION AND SURVEILLANCE
- INTERDISCIPLINARY APPROACH -
LEAs
Direction
Guidance
Intelligence
Operations
• Direction
• Planning
Exploitation
Interdiction
Interaction
Geoscience Technologists
Integrated Database
Query Database
Collect Additional Data
Initial
• Location
• Target Features
• Detection Environment
Evaluate Output
Sufficient
Not Sufficient
Select and Apply Geophysical Search Techniques
Final
• Location
• Target Features
Update Database
Surveillance

GEOPHYSICAL SEARCH TECHNIQUES

• SELECTION CRITERIA •

Scope →	Wide Area / Localized Site
Operational →	Overt / Covert
Resources →	Time / Money / Equipment
Response →	Site / Target
Effectiveness →	Select / Rank

GEOPHYSICAL SEARCH TECHNIQUES

Selection Criteria

• Response •

Target Feature	Method
Density Contrast	Gravity
Seismic Velocity Contrast	Seismic Reflection
Electrical Conductivity Contrast	EM / Electrical / GPR
Ferro-Magnetic Material	Magnetic
Grounded Conductor	EM
Seismic Noise	Seismic Monitoring
Motors / Generators	EM Monitoring

GEOPHYSICAL SEARCH TECHNIQUES

Selection Criteria

• Effectiveness •

Desirable a priori Information

- *Target Size and Depth*
- *Geology and Expected Geophysical Properties*
- *Cultural Constraints*

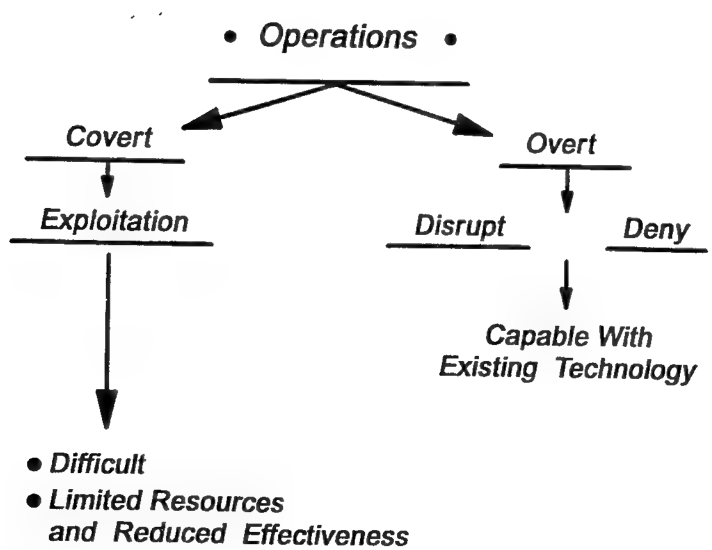
a priori Information Allows

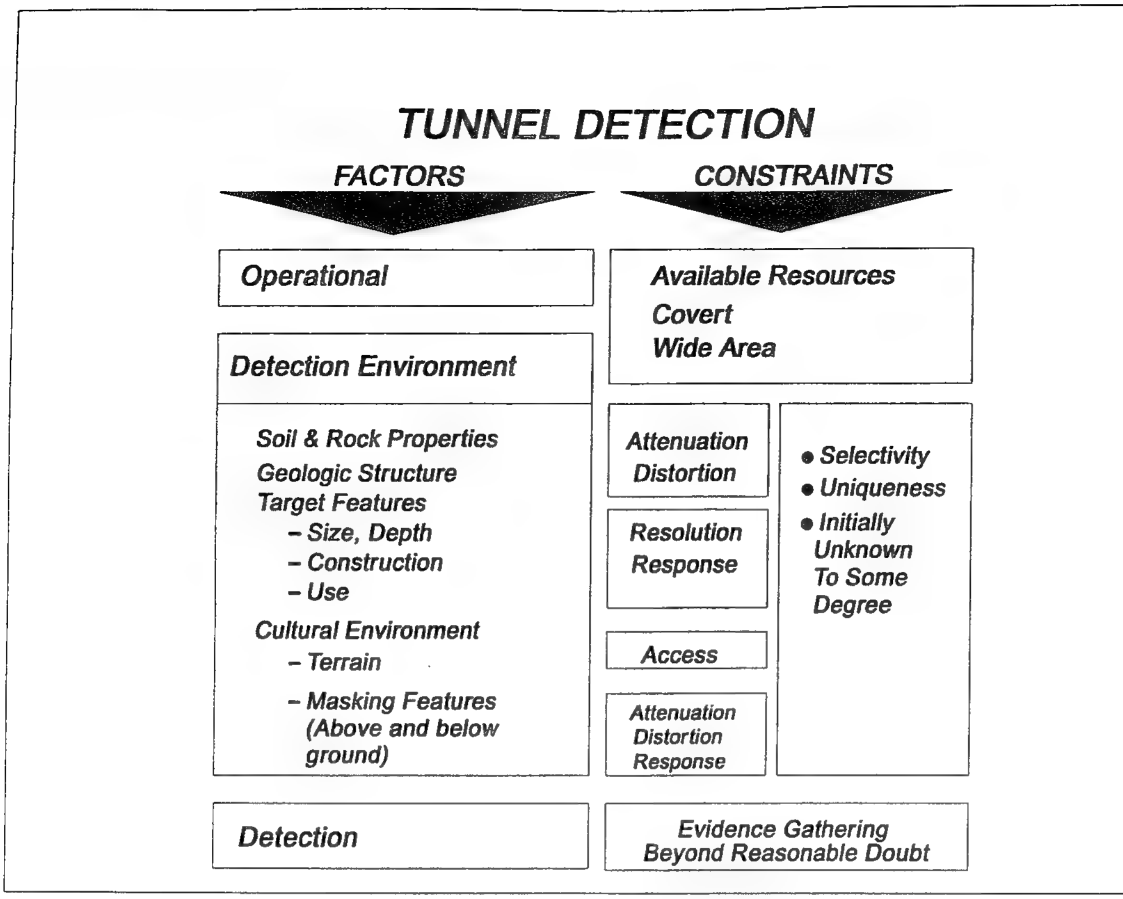
Numerical Modeling and Simulations of Selected Techniques

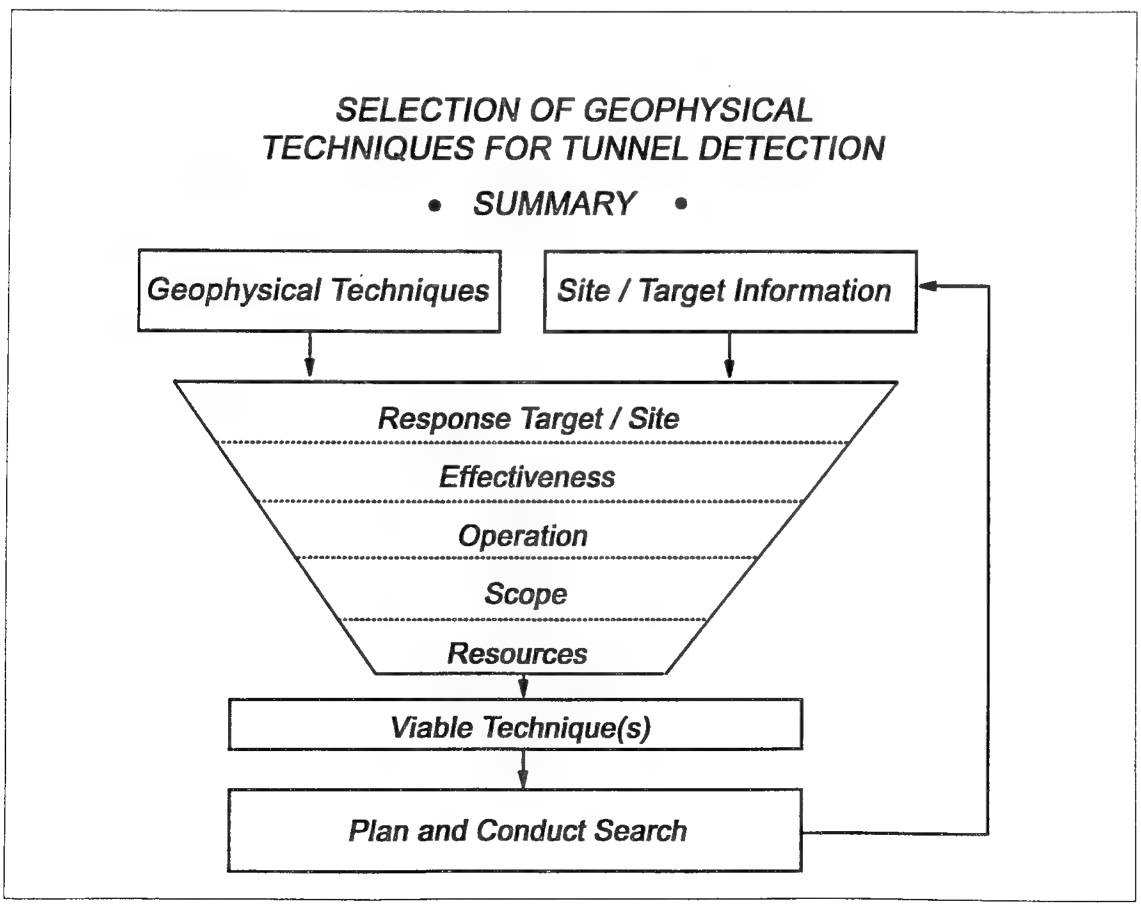
Viable Techniques
More Effective Implementation

GEOPHYSICAL SEARCH TECHNIQUES

Selection Criteria




TUNNEL DETECTION
FACTORS
CONSTRAINTS
Operational
Available Resources
Covert
Wide Area
Detection Environment
Soil & Rock Properties
Geologic Structure
Target Features
– Size, Depth
– Construction
– Use
Cultural Environment
– Terrain
– Masking Features (Above and below ground)
Attenuation
Distortion
Resolution
Response
Access
Attenuation
Distortion
Response
• Selectivity
• Uniqueness
• Initially Unknown To Some Degree
Detection
Evidence Gathering Beyond Reasonable Doubt


SELECTION OF GEOPHYSICAL TECHNIQUES FOR TUNNEL DETECTION
• SUMMARY •
Geophysical Techniques
Site / Target Information
Response Target / Site
Effectiveness
Operation
Scope
Resources
Viable Technique(s)
Plan and Conduct Search

Recommendations for Improving Tunnel Detection Capabilities

Near Term

Operation Support

Utilize Existing Technology

Future

Increase Available Resources

Research and Development

- Near Term -

Implement Integrated Tunnel Detection Methodology

- Integrated Geoscience Database
- Effective Use of Geophysical Search Technique(s)
- Integrated Use and Interpretation
- Evaluation and Integration of Use of Additional Promising Techniques
- Modification of Equipment for Covert Operation
- Establish Tunnel Detection Test Bed

Recommendations for Improving Tunnel Detection Capabilities - Future -

Research and Development

- Continued Development of Integrated Database
- Enhanced Information Management and Interpretation
  - Artificial Intelligence Modules
  - Graphical User Interface
- Develop Geophysical Methods for Covert Operation and Specific Target
  - Surface ——► Moving Platform ——► Airborne
- Develop Geophysical Methods for Wide Area Reconnaissance

OPEN DISCUSSION

A summary of the first day raised some previously unanswered questions from LEA's and strengthened discussion between LEA's and scientists. Conversations were enlightening and provided comments not addressed elsewhere in the proceedings.

LEA: How do you plan to utilize information which can be obtained from the private sector, such as oil companies?

SCIENTIST: Substantial amount of work has already been completed by major companies. Most of the time, these companies will share data if they are going to get something in return from it; that is, site characterization of a broad area. We can do that either covertly, not letting them know what we are doing, or we can be up front with them. The requirements of what oil companies must record and file vary from state to state. Information will not be available if an area is still being explored and developed. However, in a state such as Texas, there is a law requiring a company to file with the state geophysical logs of all wells they have drilled.

LEA: We tend to focus on oil, but core samples are also drilled for highway construction and to secure building permits.

SCIENTIST: State engineers' offices usually have plans that some people do not even think exist.

LEA: Private or commercial companies are a tremendous resource.

LEA: A word of caution: If scientists are going to be checking with private contractors, go through DEA or Customs because you would be amazed the amount of contacts we have established. If scientists are doing contractor checks, contact LEA first.

SCIENTIST: Our (scientist) intent is not to do anything without full knowledge of the proper personnel and agencies including Operation Alliance and JTF-6.

LEA: The scientist point of contact should be Operation Alliance. Operation Alliance will coordinate with JTF-6. Operation Alliance will make sure that FBI, DEA, Customs, and Border Patrol will be notified. When it goes to JTF-6, then it is their job to make sure that all of the DOD assets and National Guard assets are notified.

SCIENTIST: Since we are discussing information and databases, it is important to note that soils information used in the database is probably on a 1:250,000 scale. The FBI has probably one of the largest soils databases in existence with all soils typed and categorized.

LEA: If there is a need, LEA can advise the scientists how to file a support request.

LEA: With the databases and information, such as property ownership, subject to change will there be a way to update this information periodically?

SCIENTIST: Information regarding property ownership is considered secondary but desirable. Primary emphasis must be placed upon site characterization from a geologic and engineering perspective.

LEA: What would be incorporated in the database?

SCIENTIST: LEA will have to supply much of the information that goes into the database. Anything that you would like to see compiled that you can retrieve should be in the database. This will be the central depository for pertinent information.

LEA: Much of California is computerized as far as property ownership. This information is updated and put into a private database. The concern is if there is information in the database that changes, then it could be used erroneously if believed to be accurate.

LEA: Anything that is acquired should be checked.

SCIENTIST: From scientist's viewpoint, the first order of priorities would be directed toward geologic site characterization to set up that mission for looking for the underground facility. This information would lead us to plan the geophysical survey.

LEA: Is your search to find the tunnel or to say what tools to use in a certain location?

SCIENTIST: The first priority would be to build the information needed to select proper geophysical tools to search for, to detect, and to locate a tunnel in a particular location.

LEA: The first thing we (LEA) need to know are the signatures that something is being constructed.

SCIENTIST: If we do a geologic survey of a site, the subsurface material would be determined. Spoil areas with this type of material could be identified.

LEA: Purely geologically, it is unlikely we are going to do anything other than confirm the existence of something that is already rumored to be there.

LEA: Speaking of tracing construction equipment, we are dealing with two different countries. Consequently, we do not have access to information concerning the purchase of equipment in Mexico which is ultimately transported to the border area.

LEA: One other point in regard to geological surveys: Do we have to know what type of soils are present before we determine what tests will work?

SCIENTIST: In order to select the correct geophysical tools, we need a geologic survey. Having this, we can immediately rule out certain tools that will not work.

LEA: It does not take fancy concrete and shoring to construct a tunnel. The Mexicans have cheap labor and equipment and will try to construct a tunnel anywhere, even if the area is unlikely to support one. Some areas have extremely massive underground storage facilities. It includes everything from digging a hole in the ground, putting an old chest freezer in it and covering it up, to underground rooms eight by eight, ten by ten, with concrete shoring. In riverbanks, they dig very small, shallow grave type systems and cover them with brush and small amounts of timber. They are not permanent type structures. There are very few that are technically advanced with concrete and air conditioning. These people use our own system to fight against us because they know when we are up and when we are down.

LEA: How deep are these underground storage units?

LEA: They can be as deep as 30 ft, but the average is 15 to 20 ft.

SCIENTIST: Do they excavate from the ground surface to bury it?

LEA: Yes. The inside of the high dimensions are usually 6 to 8 ft. From the ceiling to the ground, depending on what they do, can be as small as 6 to 8 ins. or will have 2 to 3 ins. of concrete on top of them. The majority are approximately 1-2 ft deep under the ground and are covered with dirt and corrugated metal and wood for the ceiling.

SCIENTIST: When an area is excavated and backfilled, an anomaly would be present.

LEA: It would be difficult to determine if the anomaly is underground storage or just a garden.

SCIENTIST: A test bed is necessary to create certain conditions to determine how these can be detected.

LEA: Typically, in tunnels we have seen there will be a subterranean room at both ends for storage.

LEA: A tremendous number of subterranean rooms are being built after homes have already been constructed for hydroponics, the indoor growth of marijuana.

Research Recommendations

General

Keep simple and practical

- Emphasis on speed and covertness
- Work toward large area surveillance capability using airborne reconnaissance followed by high-resolution surface surveys
- Stay abreast of emerging technologies
  - --- Avoid duplication
  - --- Share resources
- Employ multispectral imagery
- Assess high risk/high payoff ideas
  - --- "Star Wars" approach
  - --- Balance short- and long-term needs
- Locate additional funding sources

Research Recommendations

Specific

- Establish tunnel detection test bed at Otay Mesa
- Proceed with development of complementary surface and airborne techniques
  - --- Gravity gradiometers
  - --- Navy and RimTech EM
  - --- Electrical
  - --- Magnetic
  - --- Other
- Develop affordable passive intrusion detection/monitoring devices
- Develop GIS database for suspect border sites
- Integrate intelligence information
- Apply artificial intelligence and neural networks
- Develop environmentally safe procedure for tunnel closures
- Investigate Otay Mesa site for additional tunnels

Impact on FY94 Plans Assuming Funding Cut to $100K Level

- Geologic studies to be conducted only at Otay Mesa; no other sites will be addressed
- Workshop proceedings to be published and distributed as planned
- Research needs recommendations to be drastically curtailed; emphasis only on establishment of tunnel detection test bed at Otay Mesa
- Microgravity will be only test method evaluated at Otay Mesa site to predict theoretical performance and feasibility of gradiometry concepts
- Airborne platforms will not be addressed during FY94
- Evaluation test planning of four contract deliverables only begun -- not completed
- WES tunnel detection team reduced to two members

Epilogue

Since the workshop, the scope of work for the tunnel detection project was restricted to a previously discovered tunnel in Otay Mesa, California. The people involved in tunnel investigation at the U.S. Army Corps of Engineers Waterways Experiment Station (CEWES) have been actively evaluating the Otay Mesa tunnel. The geologic team spent several weeks in February and March of 1994 describing and mapping geologic features in the tunnel. Stations were marked off every 50 ft in the tunnel for accurate interpretation. Cores were drilled at certain intervals and sent back to WES for laboratory studies including petrographic analysis, rock compressibility, and bulk density. The Bureau of Reclamation used their geophysical logging truck and equipment to record conductivity, resistivity, and natural gamma logs of the existing boreholes. This information will be correlated and described for construction of geologic cross sections and interpretation of lithologic characteristics. The results of the geological investigation will lend support when determining the feasibility of tunnel construction in a certain type of material and the method of geophysical equipment needed for detection. The geophysics team conducted investigations in April 1994 to assess the equipment most useful in detection of subsurface anomalies. Resistivity and gravity measurements were recorded along 300-ft-long profile lines centered on the axis of the tunnel. EM techniques were also utilized. After this data are processed and evaluated, the equipment best suited for a particular environment will be determined. Both the WES geologic and geophysical teams appreciate the support from Operation Alliance, JTF-6, DEA, U.S. Customs, Operation Alliance, and Border Patrol during these investigations.

The Otay Mesa tunnel site is essential as a test bed to evaluate the latest geophysical technology and hopefully, with the support of the LEA, will remain open for this purpose. Unfortunately, WES funding for FY94 was cut to $100,000, thus severely limiting the purpose and expectations of the tunnel detection effort. Although lack of funding confined the investigation to an established tunnel, future studies must be conducted elsewhere to verify what has been learned at Otay Mesa.

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13. ABSTRACT *(Maximum 200 words)*

A workshop was conducted to promote dialogue between scientists and law enforcement agents while developing meaningful research direction in the area of clandestine tunnel detection. Needs were addressed within the scope of realistic product expectation and constraints. It became apparent that a combined search strategy employing the capabilities of scientists with law enforcement experience can accelerate development of low-profile technology focused on subsurface detection of clandestine tunnels.

Scientific presentations outlined a proposed research plan to a panel of representatives from various law enforcement agencies who critiqued and offered constructive criticism. Presentations included: geologic principles, clandestine tunnel operations, modern tunneling technology (including microtunneling), a history of tunnel detection, southwest border geophysical test results from Otay Mesa, geologic criteria for selecting geophysical techniques for a site-specific search, computer applications using the Geographic Information System, and the development of a search strategy. Panel discussions covered conditions and tactical constraints faced by scientists operating along the southwest U.S./Mexico border.

The workshop opened two-way communication for the exchange of ideas between scientists and law enforcement agents. Its primary accomplishment was a workable search strategy which can be supported jointly by law enforcement agents and the scientific community.

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